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TIME DOMAIN RADAR LABORATORY OPERATING SYSTEM DEVELOPMENT AND T--ETC(U)

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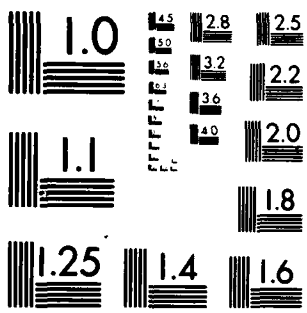

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Monterey, California

THESIS

TIME DOMAIN RADAR LABORATORY OPERATING
SYSTEM DEVELOPMENT AND TRANSIENT
EM ANALYSIS

by

Ludwig A. Sorrentino

September 1981

Thesis Advisor: M. A. Morgan

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An operator-microprocessor interactive Operating System has been developed for the Time Domain Radar Laboratory (TDRL). The Operating System performs signal acquisition and averaging, real time and frequency domain computations and provides outputs in easily evaluated graphic displays. Target classification is made by analysis of either impulse, step or ramp responses. A noise-reduction signal optimization technique is implemented. Numerous measurements of known and unknown targets are made using various antennas

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Time Domain Radar Laboratory Operating System Development and Transient EM Analysis

by

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Lieutenant Commander, United States Navy
B.S.O.E., United States Naval Academy, 1971

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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September 1981

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ABSTRACT

An operator-microprocessor interactive Operating System has been developed for the Time Domain Radar Laboratory (TDRL). The Operating System performs signal acquisition and averaging, real time and frequency domain computations and provides outputs in easily evaluated graphic displays. Target classification is made by analysis of either impulse, step or ramp responses. A noise-reduction signal optimization technique is implemented. Numerous measurements of known and unknown targets are made using various antennas and results are compared to theory. Targets are classified. Antenna parameters are established. Algorithms using the specialized features of the host Graphic System are tailored to the requirements of the TDRL for a detailed graphic presentation of processed data.

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I. INTRODUCTION

A. OVERVIEW

Briefly stated, direct time-domain techniques for transient radiation and scattering are broadly concerned with the response of some object of interest, either equipment or a target, to non-monochromatic electromangetic sources. The analysis is done in the time-domain, with time treated as an explicit independant variable in most methods.

In the past, frequency domain analysis has been the primary means of analyzing non-monochromatic EM phenomena. Time-domain solutions in closed-form were almost impossible to obtain, except in certain very simple cases. The amount of computational work required was correspondingly significant. No practical aides were available to assist in performing the operations prior to the development of fast computer systems.

Another limitation was the requirement that the time-domain response be as nearly an impulse as possible and thus possess a broad band of frequencies. Hardware was required to produce very short pulse waveforms.

The situation changed radically with the widescale introduction of computers capable of performing rapid computations involving large numbers of iterations in relatively short periods. This, coupled with the rapid maturing of short-pulse hardware technology, soon made possible the application of time-domain techniques to a wide variety of eletromagnetic problems.

Miller and Landt [Ref. 1] list some advantages of direct time-domain solutions over frequency domain treatments of transient problems. They are:

1. Greater solution efficiency for many types of EM problems.
2. More convenient handling of non-linearities.
3. Improved physical insight and interpretablility of EM phenomenon.
4. Availability of wide-band information from a single calculation.
5. Opportunity to isolate interactions, using time range gating (e.g., pulse reflections from distant objects not of interest, etc.,).

The major disadvantage is the increased complexity of the computer implementation of a time-domain program as opposed to one involving frequency domain techniques. There is also a corresponding difficulty in the software development and its practical use. Finally, the computational time may be significantly greater than that required of other techniques.

The applications for time-domain techniques are diverse. Transient analysis can be used to directly evaluate the transient characteristics of new antenna designs, determining such parameters as driving point currents, radiated far fields and near fields, and assisting in determining antenna gain. These methods may also be used in determining the degree of coupling due to electromagnetic pulses (EMP) generated because of lightening during a nuclear detonation. Finally, time-domain techniques may be directly applied in the solution of the inverse scattering problem involving the receiving and scattering properties of a large category of target types.

As time-domain transient techniques are further refined, it can be expected that a greater number of uses will be identified.

B. REVIEW OF TRANSIENT EM ANALYSIS TECHNIQUES

There are three broad categories of techniques identifiable in the literature involving transient analysis.

They are direct (time-domain) techniques, transform (frequency domain) techniques, and hybrid techniques. [Ref. 2] This report is only interested in direct techniques and will not review the others.

1. Physical Optics Inverse Scattering

The earliest techniques developed involved physical optics inverse scattering. Kennaugh and Cosgriff [Ref. 3] in 1958 proposed that the impulse response of a scattering, conducting body is simply the second derivative of the projected area function of the body if physical optics currents are postulated on the surface. If a target is illuminated with an incident ramp plane wave, then the projected area function of the target is directly proportional to the far-scattered ramp response. This is only an approximate relationship, however, since it is based on the assumption of physical optics currents.

A more direct and precise ramp response technique was suggested by Kennaugh and Moffat [Ref. 4] in 1965. They predicted satisfactory approximate ramp response signatures could be obtained with narrower bandwidth interrogating signals than that required for the impulse response.

The above techniques were generally applicable for targets which were rotationally symmetric and for whom the direction of the electromagnetic field incidence was axial. In 1976, Young [Ref. 5] demonstrated that a volume estimate can be obtained from the ramp response waveform. He further extended the ramp response technique to arbitrarily shaped targets with the incident field being other than axial.

2. "Exact" Inverse Scattering Method

Another method which improves upon the physical optics inverse scattering theory is the "exact" inverse scattering method first suggested by Bennett et. al., [Ref. 6] in 1974, and further refined in 1977. [Ref. 7] The inverse scattering problem is solved using an inversion of a space-time integral. The method takes into account the backscatter response of the target, the direct effect of the incident electromagnetic field, and the correction currents flowing on the target surface. Theoretically, by completely describing the interactions of the two components of the surface currents, a close approximation of the target shape is possible. The actual implementation is limited to "perfectly" conducting scatterers. It is this method which has been selected for use in the Naval Postgraduate School Time Domain Radar Laboratory (TDRL).

3. Other Methods

Other methods that have been developed, although to a less satisfactory degree of accuracy than the inverse scattering methods, include radar target identification methods. Only a finite number of solutions (targets shapes) are allowed as opposed to the nearly infinite number possible using inverse scattering. The models of targets are stored for parameter comparison with actual returns. Certain parametric aspects of a wideband illuminating signal, such as natural resonance frequencies and polarization of the return, are used. Other similar methods use amplitude and phase differences or special properties of Rayleigh region scattering. All these methods are limited in practical application.

Still another important and powerful method considers multifrequency target illumination using existing radars to simultaneously illuminate targets with VHF, UHF, L and S band radar frequencies with circular polarization. [Ref. 8] Circular polarization eliminates any polarization angle dependance the signal might have. This approach allows for the inclusion of all radar system parameters (such as antenna gain, noise level, range, etc.) in the identification algorithm. The technique further demonstrates that the target shape information may be obtained with a high degree of accuracy from radar systems correctly tailored to the problem of general target identification.

C. REVIEW OF TDRL PROGRESS AT NPS

Three requirements were initially identified. First, a method had to be chosen from the techniques listed above. Secondly, the construction of a physical laboratory to perform the required measurements in support of the chosen technique had to be designed and built. Thirdly, an alogorithm had to be developed employing the selected technique for laboratory use.

As stated above, the "exact" inverse scattering method suggested by Bennett was the scheme chosen. To support this, work began in January 1980 where evaluation of various designs to be used in constructing a Time Domain Radar Laboratory at the Naval Postgraduate School was carried out by Capt. C. W. Hammond, USMC, as a thesis project. Work was essentially completed with the erection of the laboratory and interfacing of hardware in September, 1980. [Ref. 9]

In support of the TDRL, LCDR Meir Morag, Isreali Navy, began, as a thesis project, the development of an "exact" inverse scattering algorithm in September, 1980. The algorithm was completed in March 1981 [Ref. 10] However, the program was developed in FORTRAN, a language not used by the TDRL computer system. A translation to BASIC and adaptation of the code was necessary to reduce memory storage requirements and to ensure computational times were of reasonable lengths.

The final step in the establishment of the TDRL was the validation of the laboratory in confirming the work of Hammond and Morag. This is one of the principal aims of this project.

D. THESIS OBJECTIVES

The objectives of this thesis are to:

1. Develop a working software program which will acquire and prepare transient response data from various targets for input to the time-domain integral equation.
2. To show that through signal processing, the effects of the receiving antenna can be neglected, and the response to arbitrary specified exciting waveforms can be constructed, or "synthesized", using FFT techniques.

3. Validate the TDRL.

The main effort has been directed toward the development of a user oriented computer program which will allow the determination of the second objective and prepare the transient domain data for input into the numerical time-domain integral equation. The shape of the object being observed is displayed both before and after correction factors are applied. The shape of the object was developed from the ramp response of the impulse function applicable to the target. The program was also made compatible with the input of data to an alternate natural resonance frequency target identification technique, using Prony's method, which is being developed by LT Demetrius Papaspiridakos, Hellinic Navy, as a thesis project.

This report first describes the physical structure of the TDRL. It then derives the relevant time-domain integral equations for both the radiation and inverse scattering solution for simple axisymmetrical, perfectly conducting, closed surfaces in Chapter III. Next, it discusses and develops the numerical solutions to the integral equations. In Chapter V, the implementation of the complete computer code is presented. And finally, measurements that are relevant to the validation and confirmation of previously developed concepts are reported.

This thesis is the third to be produced for this major project at the Naval Postgraduate School. It marks a point of departure in that essentially all the preliminary work which will allow for the effective use of the TDRL has been performed with validation. The laboratory is, for the most part, ready for applied research involving transient time-domain analysis.

II. PHYSICAL DESCRIPTION OF TDRL

A. INTRODUCTION

As stated in Chapter I., the primary thrust of this work is to provide a practical working alogorithm to serve as the principal link between the acquisition of transient data for targets situated on the TDRL scattering range, and the use of that data in the inverse scattering algorithm.

The work performed on this project is a direct extension of the preliminary work performed by Hammond in the construction of the Naval Postgraduate School Time Domain Radar Laboratory (TDRL), and by Morag in the development of the numerical integral equation algorithm for the solution of the inverse scattering problem involving axisymmetric targets.

The results obtained by Hammond and Morag are essentially complementary. However, the independant approaches each took in their work, particularly in the selection of unrelated processing machines for data processing, made necessary certain practical modifications to the TDRL. It is germane to review the basic work of Hammond and discuss those modifications made. Such a review will also allow for the setting of a frame of referance to aid in the explanation of the linking algorithm developed and results obtained in this project.

B. PHYSICAL DESCRIPTION OF TDRL

The physical set-up of the TDRL is shown in Figure 2.1. As can be seen, the TDRL can be broken functionally into three groups:

1. The Impulse Generator Source Group
2. The Imaging Plane Group
3. The Sampling Receiver and Signal Processing Group

Basically, the TDRL is an open system designed to determine the transfer function of a target from its backscattered radiation. Scattering measurements are bi-static. A description of each functional group follows.

1. Source Group

This group consists of a single item, a Video Communications UHF Impulse Generator, Model 1000. This generator is the source of the transmitted pulse and also provides the triggering signal which synchronizes the Signal Processing Group to the transmitted signal.

The Impulse Generator is specified to provide a fixed amplitude 45- volt pulse with a maximum rise time of

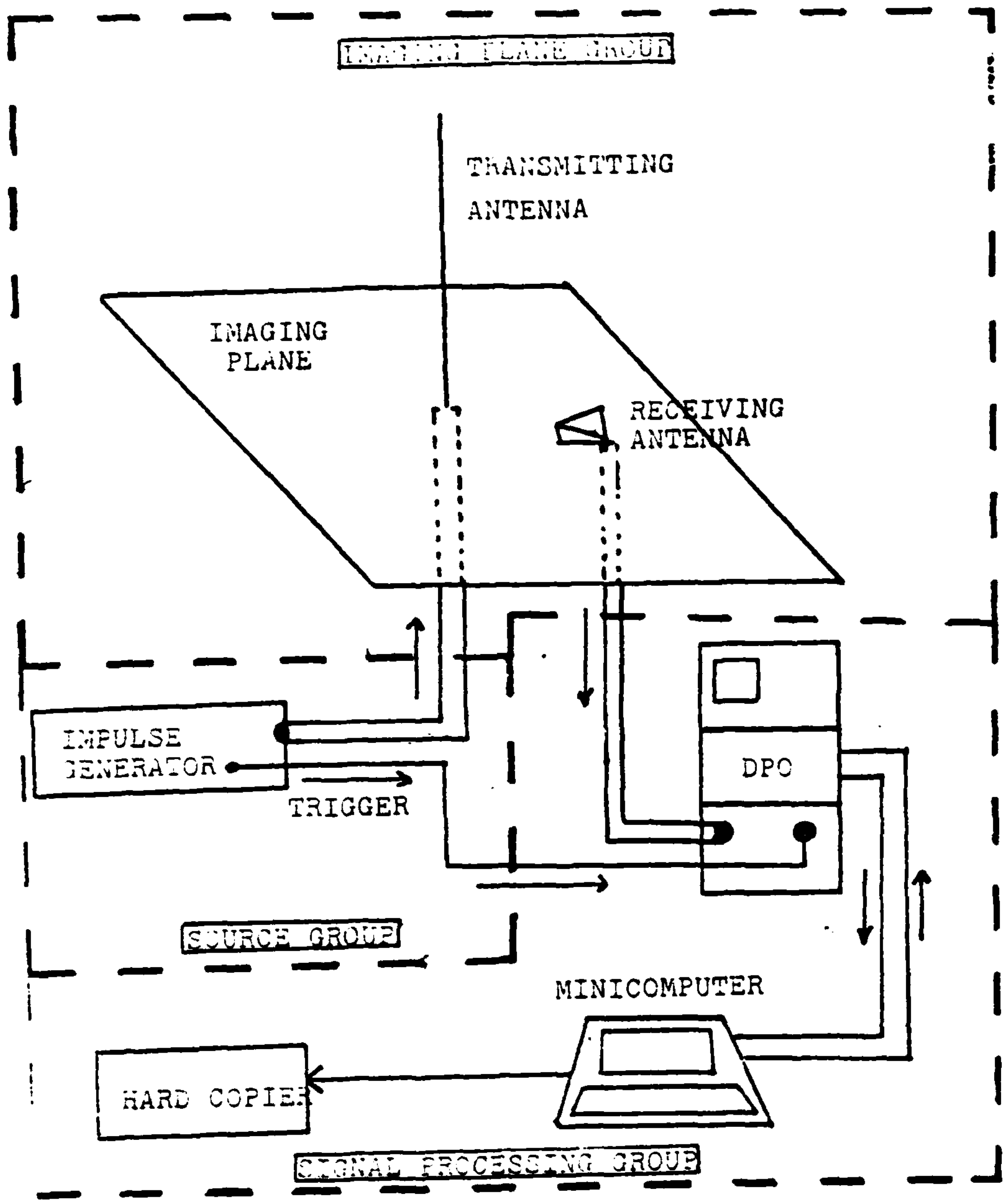


Figure 2.1. Time Domain Radar Laboratory

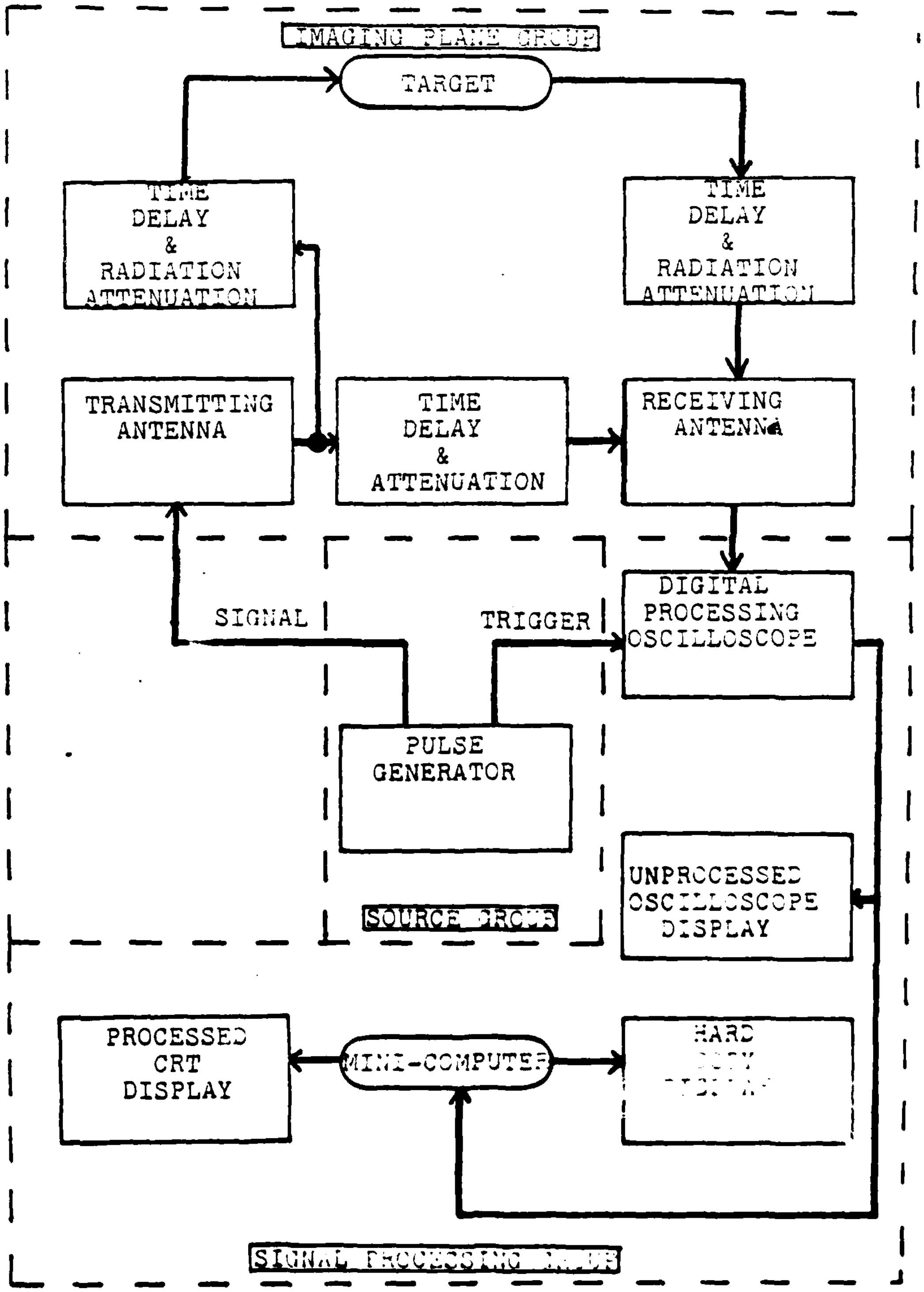


Figure 2.2. Block Diagram of TDRL

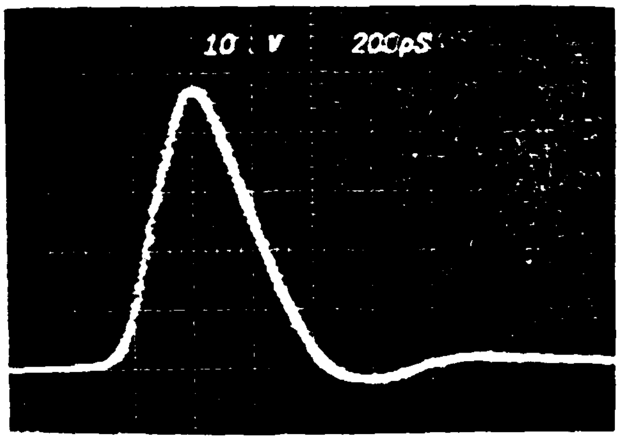


Figure 2.3. Source Pulse from Generator

370 picoseconds. Figure 2.3 is a typical waveform as measured on a Tektronix S-6 Sampler Head by the manufacturer.

The output of the Impulse Generator as measured at the TDRL as measured by the Operating System is given in Figure 2.4, and Figure 2.5 as photographed from the DPO directly. To set full waveform presentation on the measuring oscilloscope, 30dB attenuation was applied to the generator output. Taking the attenuation into consideration, the measured peak value of voltage (1.4604 volts) gives the actual output of the generator to be 46.2 volts. This is about 3% better than rated. The rise time of the output is

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	1	6-26-81	N/A	H0	???	GENERATOR WAVEFORM

MAXIMUM PEAK VALUE (VOLTS)	1.1284
MINIMUM PEAK VALUE (VOLTS)	-0.3320
RMS VALUE (VOLTS)	0.4214
MEAN VALUE (VOLTS)	0.0000

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0

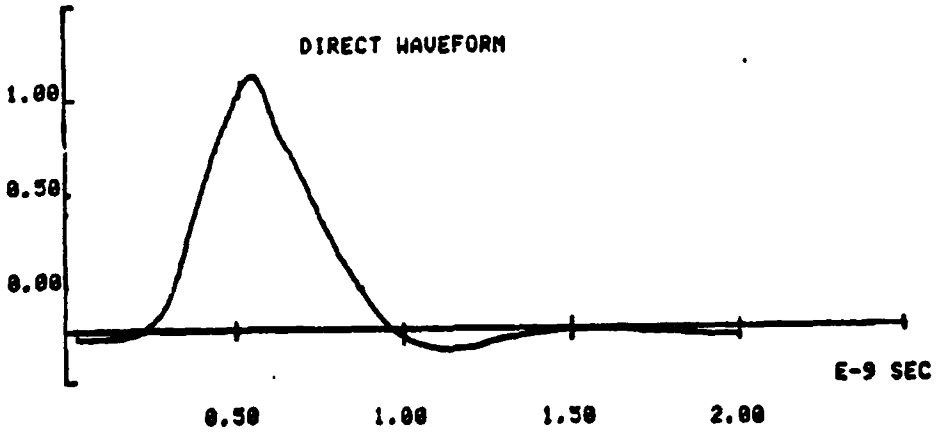


Figure 2.4. Source Waveform Measured at TDRL

about 250 picoseconds, also better than specified by the manufacturer, by about 48%.

Some notable features of the generator used in TDRL measurements are a variable trigger repetition rate from 10 Hz to 1 MHz and an adjustable delay from 50 to 150 nanoseconds. All outputs are matched into a 50-ohm load. The generator allows rapid acquisition of highly coherent, repetitive waveforms. This is an important feature when attempting to maximize signal-to-noise ratio through signal averaging.

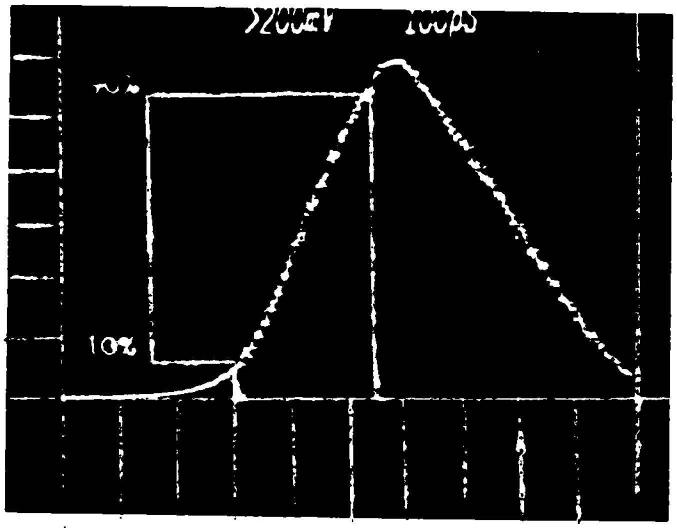


Figure 2.5. DPO Waveform--UHF Impulse Generator

The Video Communications Impulse Generator replaces a Tektronix Type 109 impulse generator used by Hammond. The completely solid-state electronics of the Mark 1000 has proven more reliable in producing a relatively noiseless, pulse-to-pulse coherent signal than did the reed-switched Type 109. The Type 109 had a fixed pulse repetition rate at about 720 pulses per second. This is a very limiting factor when attempting to noise average a signal.

The impulse source is connected to the transmitting antenna via a 3.2 meter RG-8A/U coaxial cable. This cable serves both as a conductor of the source pulse and a short delay element to the transmitted signal.

2. Imaging Plane Group

The Imaging Plane Group consists of four elements the transmitting antenna, the receiving antenna, the target, and the imaging plane.

a. Transmitting Antenna

The transmitting antenna is a 6.4-meter endfed monopole. It extends vertically from the ground plane and produces a vertically polarized EM field.

b. Receiving Antenna -- Transverse Electromagnetic Horn (TEM)

Hammond explored a variety of receiving antenna types to be used in the TDRL. The most useful is the TEM horn antenna in that it has the following advantages over the other antennas considered:

1. Better directivity.
2. Less Attenuation.
3. Mobility on the image plane.
4. A readily variable characteristic impedance.
5. Relatively frequency independant over a wideband.

The TEM Horn used in the TDRL is physically an open sided pyrimidal structure when deployed. It is a single piece of flat copper, about 1mm thick and triangular in shape. Figure 2.6 gives the relevant dimensions. The

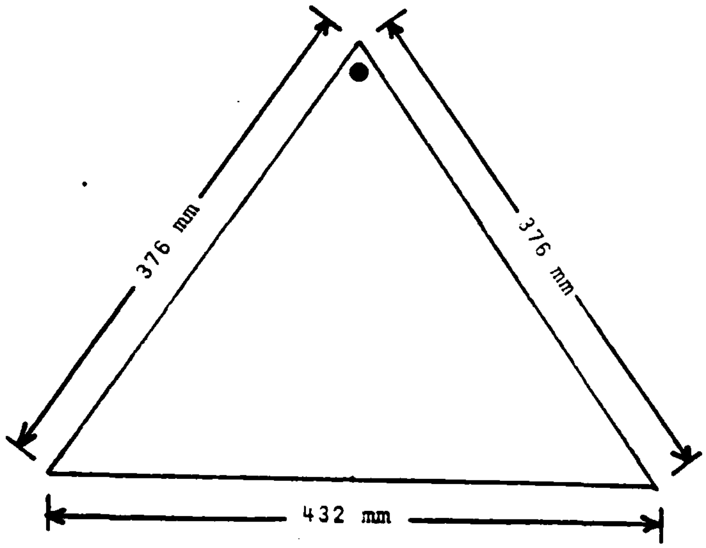
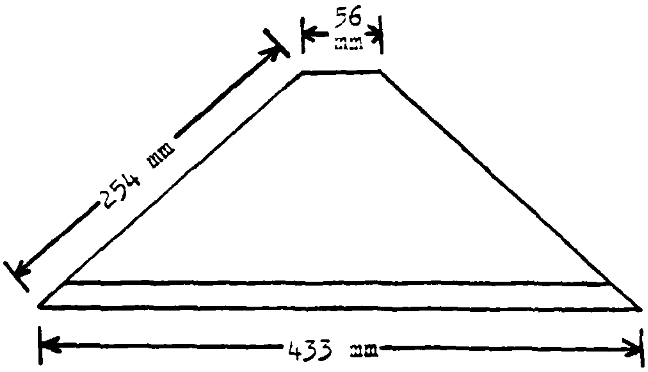


Figure 2.6. TEM Horn Dimensions

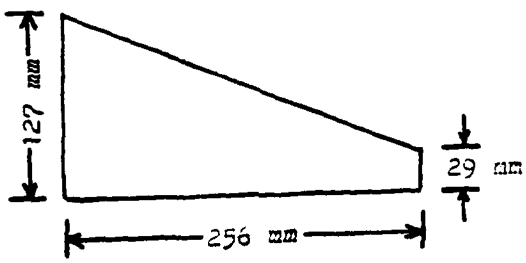
hole at the apex of the antenna allows for connecting to the receiving cable.

The receiving horn antenna is mounted in a three dimensional trapezoidal support mount with quarter-inch plexiglass walls on the top, bottom, and sides. The front and rear are open to allow easy insertion of the copper plate. The dimensions and shape of the mount are given in Figure 2.7 All dimensions are outside wall measurements.

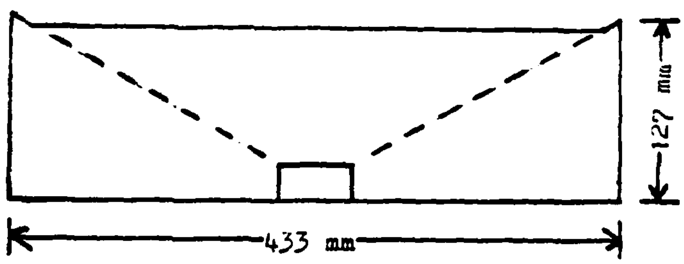
The flat copper antenna is slipped into the front of the plexiglass mount and protrudes through the back. A coaxial cable is connected to the back with an rf



a. TOP



b. SIDE



c. FRONT

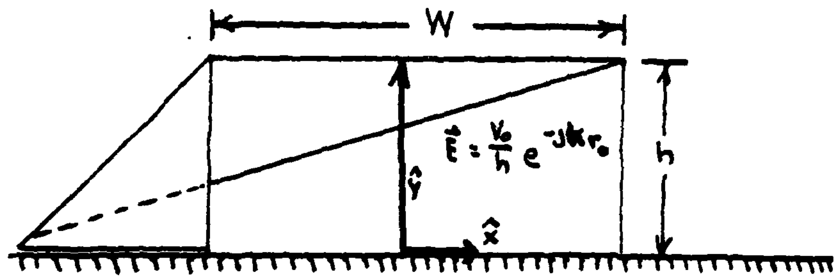
Figure 2.7. TEM Horn Support Mount Dimensions

end-connector and hand-tightened screw. See Figure 2.13 for a diagram of the assembly of the connection point. The antenna is physically supported within the mount by grooves cut into and running along the length of each side. The grooves serve to fix the flare angle of the antenna at approximately 24.1°.

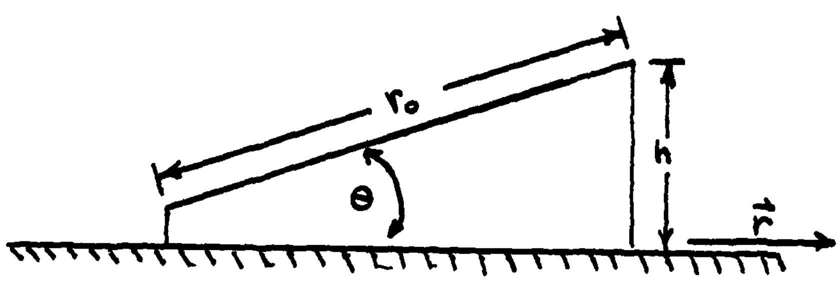
The dimensions of the mount were chosen for reasons of practicality, being the most appropriate for the material available and providing a reasonable flare angle and antenna characteristic impedance for signal reception. The mount also provides stabilty to the Horn under various weather conditions. Thus, by placing the horn in the plexiglass support mount, physical and electrical characteristics are fixed, assisting in correlating run to run measurements. The TEM Horn as it would be mounted on the imaging plane is drawn in Figure 2.8. The support mount is not shown for clarity.

The addition of the plexiglass mount should have negligible effect on the received signal. Figure 2.9 shows the response of the supported horn antenna to a pulse generated by the source. This compares favorably with the pulses obtained by Hammond without the plexiglass mount. [Ref. 11]

As noted in Figure 2.8, the electric field at the aperture of the horn, assuming a uniform TEM wave being excited between the horn and the ground plane, is given by:



(a) Front View



(b) Side View

Figure 2.8. TEM Horn Receiving Antenna

$$\vec{E} = \frac{V_o}{h} e^{-jkr_o} \qquad (2.1)$$

where: V_o = amplitude of the incident voltage at the feed point.

h = height of aperture

k = wave number = $2\pi/\lambda$

r_o = distance of observer from the referance point.

It can then be easily shown that the receiving antenna impulse response in the far field is: [Ref. 12]

$$S^r(t) = -c\,\varepsilon_o\,WZ_L\,\delta\,(t - r_o/c) \qquad (2.2)$$

where: δ = impulse

Z_L = load impedance

and the impulse response of the transmitting antenna is:

$$S^t(t) = -\frac{60\varepsilon_o W}{r}\,\frac{\partial}{\partial t}\,\delta\,(t - r_o/c)$$

where: r = distance from the aperture to an observer on the image plane in the boresight direction.

Thus the transmitting impulse response is simply the time derivative of the receiving impulse response. The impulse response is a delayed impulse, delayed in time by r_o/c, and multiplied by a negative constant which is dependant on the width of the antenna aperture, w, and the load impedance Z_L.

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	1	6-26-81	N/A	H0	???	GENERATOR WAVEFORM

MAXIMUM PEAK VALUE (VOLTS)	0.2528
MINIMUM PEAK VALUE (VOLTS)	-0.0932
RMS VALUE (VOLTS)	0.0796
MEAN VALUE (VOLTS)	0.0000

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0

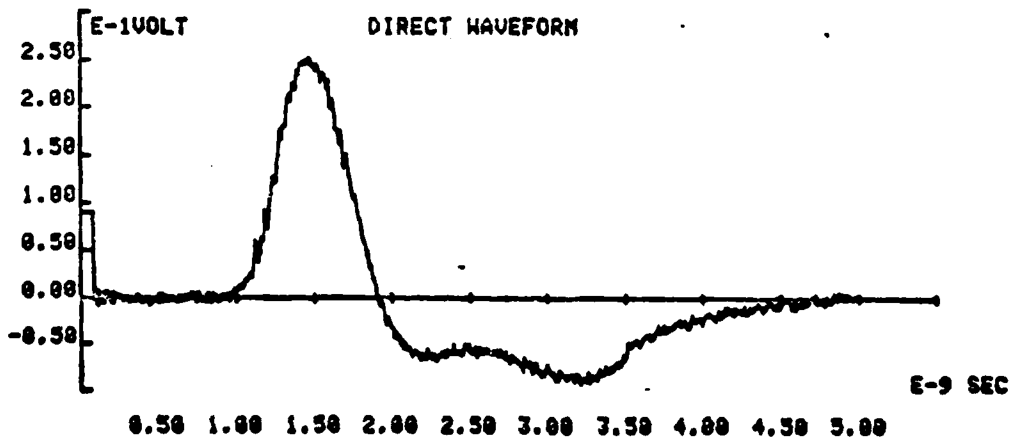


Figure 2.9. Typical TEM Horn Received Waveform

Generally, the following limitations are applicable to the TEM Horn during most TDRL measurements: [Ref. 13]

1. The antenna is not in the far field of the transmitting antenna.
2. The flare angle of the TEM Horn is not wide enough to receive energy from all positions along the transmitting antenna.
3. Wavelengths at high frequencies may not propagate in a true TEM mode, resulting in attenuation and distortion.

The net result is a deviation from the ideal results of the impulse responses as stated above. When Figure 2.9 is compared with Figure 2.4, distortion of the pulse as received by the antenna is noted. However, for TDRL purposes, the reproduced waveform is still reasonably faithful to the original source pulse.

c. Receiving Antenna -- Monopoles

Monopole antennas are also used on the TDRL scattering range. One of eleven monopoles, ranging in length from 85 millimeters to 285 millimeters, in 20 millimeter lengths, can be chosen. Each monopole is constructed of brass rod and is threaded on one end to allow for ease of connection to the receiving elements.

The monopoles may be considered center-fed dipoles with their images in the ground plane. In effect, they are oscillating electrical dipoles in free space. Oscillation at frequencies related to the quarter-wavelengths of the monopoles is to be expected.

Figures 2.10, 2.11 and 2.12 confirm the above. The effects of radiation damping, dispersion and reflection due to the impedance discontinuity of the antenna are clearly demonstrated. From Figure 2.4 the pulse width of the source pulse is seen to be about 1.2 nanoseconds. This corresponds to a wavelength of about 360 millimeters.

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	4	6-29-81	1.27M	2	???	ACQUIRE 85MM ANTENNA RESPONSE

MAXIMUM PEAK VALUE (VOLTS)	0.0577
MINIMUM PEAK VALUE (VOLTS)	-0.0702
RMS VALUE (VOLTS)	0.0237
MEAN VALUE (VOLTS)	0.0000

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0

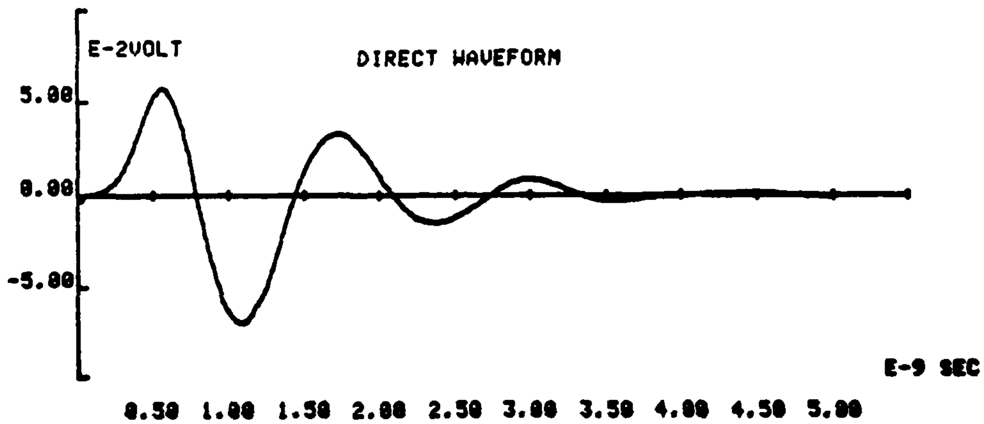


Figure 2.10. 85mm Monopole Pulse Response

Figure 2.10 is the short-pulse response of the 85mm monopole. This antenna is almost exactly one quarter-wavelength in height in relation to the source pulsewidth. It correspondingly produces a nearly pure sinusoidal variation, damped in time, as predicted by classical antenna theory.

Figures 2.11 and 2.12 are the observed responses for the 185 millimeter and 285 millimeter monopoles. As can be seen, the antennas tend to resonate at their quarter-wavelength periods of 2.5 and 3.8 nanoseconds

TARGET: RUN DATE DIST ANT TGT REMARKS
3 6-29-81 1.27M 7 ??? ACQUIRE 185MM ANTENNA RESPONSE

MAXIMUM PEAK VALUE (VOLTS)	0.0859
MINIMUM PEAK VALUE (VOLTS)	-0.0907
RMS VALUE (VOLTS)	0.0320
MEAN VALUE (VOLTS)	0.0000

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0

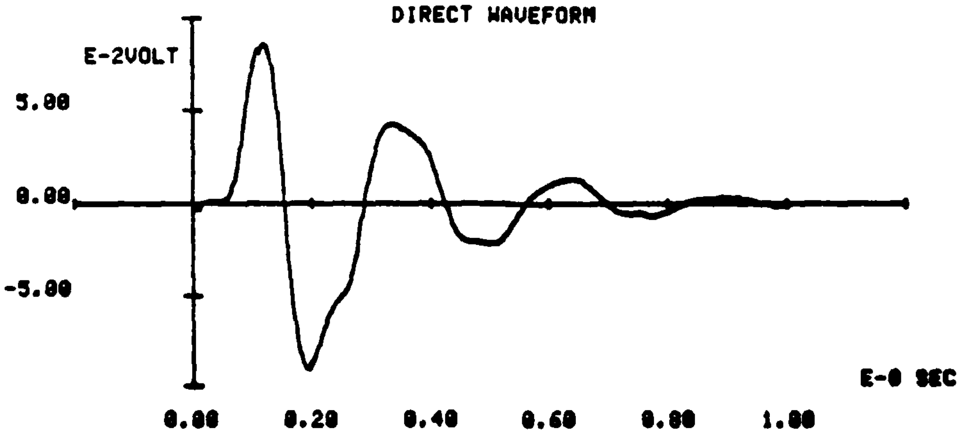


Figure 2.11. 185mm Monopole Pulse Response

respectively. Although the amplitudes of these two monopoles do not differ greatly (less than .08% between their maximum peak values), the longer antenna tends to distort the incident wave to a greater extent. This is most readily observed when comparing the root-mean-square voltages of the two waveforms. The 185 millimeter antenna provides more effective power to the receiving circuits than does either of the other two monopoles. The 285 millimeter antenna dissipates a considerable amount of energy in the long period oscillations; the 85 millimeter antenna is too small to acquire the full power of the transmitting antenna. There may then be a "best" monopole length for a particular source pulse. What this length might be and whether the monopoles are selective of targets according to their dimensions will be discussed more fully in Chapter V.

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	2	6-29-81	1.27M	12	???	ACQUIRE 285MM ANTENNA RESPONSE

MAXIMUM PEAK VALUE (VOLTS) 0.0861

MINIMUM PEAK VALUE (VOLTS) -0.0934

RMS VALUE (VOLTS) 0.0289

MEAN VALUE (VOLTS) 0.0000

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0

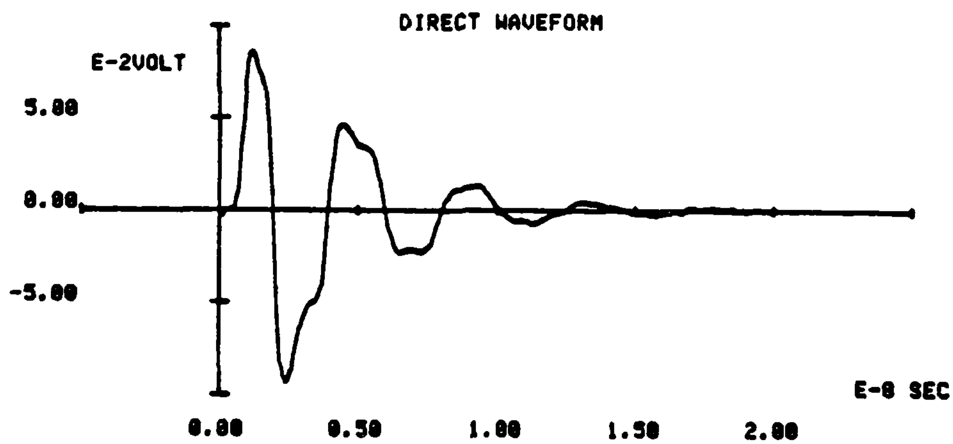


Figure 2.12. 285mm Monopole Pulse Response

All receiving antennas are coupled to the Signal Processing Group through a coaxial end-coupling fitted through the imaging plane. The connection point is diagrammed in cut-away in Figure 2.13. The antenna is

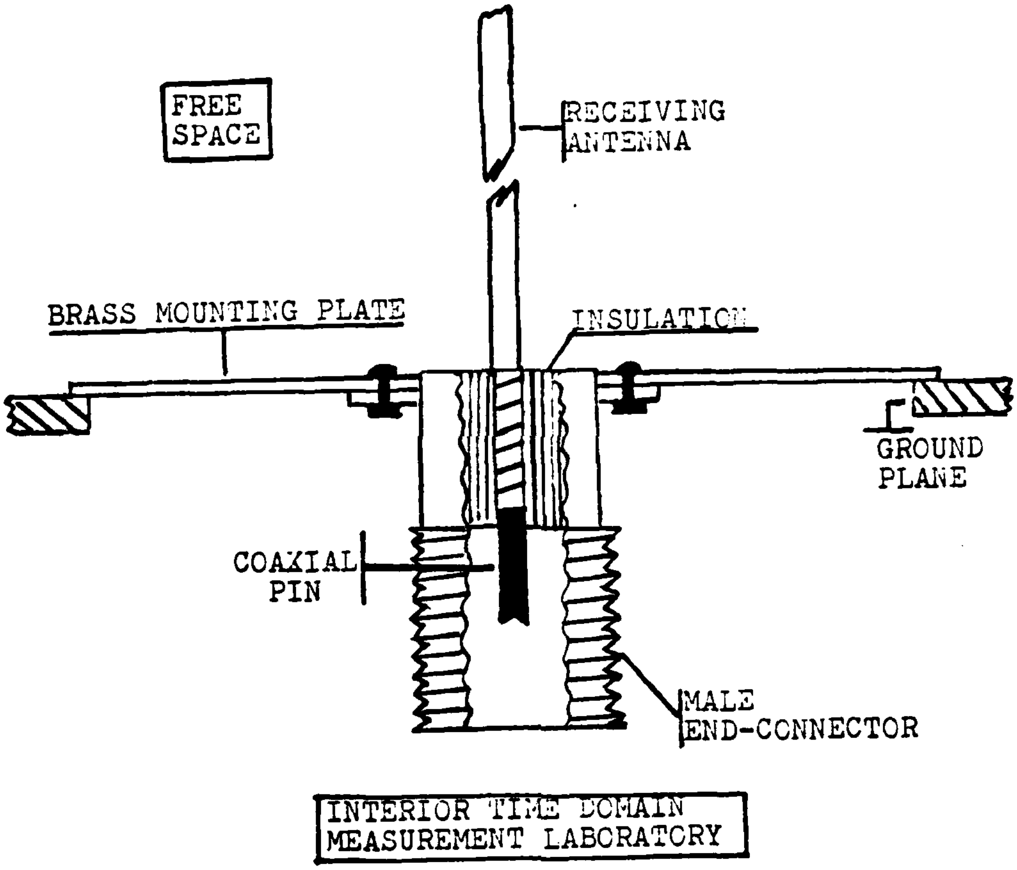


Figure 2.13. Receiving Antenna Connection Point

coupled as close to the ground plane as possible. This is particularly important for the TEM Horn to prevent undesirable oscillations. As drawn, the threaded portion of the monopole (or hand tightened screw of the TEM Horn) is joined to a connector pin by butting the surfaces of the antenna and pin together. A coaxial cable is then connected to the end connector and the rf signal is transferred to the receiving circuits.

This arrangement has worked well. No reflections or excessive attenuation of the incoming signal due to the joint were observed. Oscillations on the TEM Horn were minimal.

Table I lists the antennas currently available to the TDRL user. The significant dimensions and pertinent characteristics are reviewed.

d. Targets

The targets used on the TDRL scattering range are of various dimensions. Currently, eleven are used in imaging experiments. They are all axisymmetric, closed surfaces with edges and vertices. The targets may be broken into three catergories according to general shape:

1. Half-cylinders
2. Half-spheres

TABLE I

TDRL Antennas

ANTENNA NUMBER	DESCRIPTION	DIMENSIONS	COMMENTS
1	TEM Horn	Figure 2.6	Broadband
2	Dipole	85mm	Oscillating Dipole
3	Dipole	105mm	
4	Dipole	125mm	
5	Dipole	145mm	
6	Dipole	165mm	
7	Dipole	185mm	
8	Dipole	205mm	
9	Dipole	225mm	
10	Dipole	245mm	
11	Dipole	265mm	
12	Dipole	285mm	

3. Half-cones

Table II lists the targets and provides general information about each.

There are six half-cylinders used as targets. They are all machined from aluminum stock. The largest is 12-inches long with a 3-inch radius. The smallest is 3.06-inches long and 1.5-inches in radius.

A single half-cone is also used as a target. The cone is machined from the same stock as the half-cylinders.

Four spheres, varying in radius from 5-inches to 1.5-inches are the four remaining targets. The spheres are basically styrofoam balls cut in half. Each half is covered with heavy-duty aluminum foil to provide the proper reflection of transient EM.

Each of the targets, when placed on the ground plane, appears to the incident pulse to be mirrored. Therefore, the receiving antenna sees not the half-shapes, but the full cylinder, cone or sphere.

No particular problems were noted when using the targets except for the need to anchor the spheres with weights during inclement weather. Otherwise, they have a tendency to move on the plane due to the wind.

e. Image Plane

The final element of the Image Plane Group is the image plane itself. It is a square structure of welded Reynolds Type AN-190 aluminum sheet. It measures about 11 meters on a side for an area of about 121 square meters. It is four millimeters thick.

Based on the above, the range clear time, which establishes the low frequency cut-off of the measurement, is greater than 36 nanoseconds. The clear time establishes the first arrival at the measurement point of a reflection from objects surrounding the plane and the end of the plane.

TABLE II

TDRL Targets

TARGET	TYPE	RADIUS	LENGTH	MATERIAL
1	Cylinder	3"	12"	Aluminum Stock
2	Cylinder	1.5"	12"	Aluminum Stock
3	Cylinder	3"	6"	Aluminum Stock
4	Cylinder	1.5"	6.06"	Aluminum Stock
5	Cylinder	3"	3.06"	Aluminum Stock
6	Cylinder	1.5"	3.06"	Aluminum Stock
7	Sphere	5"		Al and Styrofoam
8	Sphere	4"		Al and Styrofoam
9	Sphere	3"		Al and Styrofoam
10	Sphere	1.5"		Al and Styrofoam
11	Cone	3.18"	5.94"	Aluminum Stock

The main purpose of the image plane is to isolate the targets and the antennas from the underlying structure of the TDRL. Instrumentation cables are introduced from under the ground plane and are thus kept from interfering with the measurement. The plane also serves as the primary support structure for both the transmitting and receiving antenna.

No significant problems were encountered with the image plane. However, some disadvantages of this plane arrangement are that only objects having a symmetry plane can be measured, and polarization and incident angles are limited. But, for the work intended, the image plane serves its purpose well.

3. Sampling Receiver and Signal Processing Group

The Signal Processing Group consists of three elements:

1. Digital Processing Oscilloscope (DPO)
2. Mini-Computer
3. Hard Copier

The Signal Processing circuits are connected from the output of the receiving antenna to the input of the DPO via 2.58 meters of RG-8A/U coaxial cable. The cable provides some attenuation and delay of the source signal provided by the impulse generator. Additionally, a trigger signal is sent to the DPO from the pulse generator via .54 meters of RG-58C/U cable.

The lengths of the signal and trigger cable are chosen for convenience and for minimum attenuation. They may be varied for special purpose applications such as to accommodate a different trigger source by providing a necessary delay. Care must be taken not to introduce too much delay or the received signal will not be windowed on the CRT display of the DPO. The maximum practical length of cabling, including that to the transmitting antenna from the pulse generator, should be less than 20 meters for the current equipment configuration of the TDRL.

a. Digital Processing Oscilloscope

The Tektronix Digital Processing Oscilloscope is a computer compatible, analog to digital system. It is comprised of two elemental units; a Tektronix 7704A General Purpose Oscilloscope System, and a P7001 Processor. Modification of the 7704A Oscilloscope by the addition of various plug-in modules allows for tailoring of the whole DPO system to the specific needs of the TDRL. A cursory description of the various elements of the DPO, as applicable to the TDRL, follows.

The 7704A Oscilloscope system is composed of two parts; the D7704 Display Unit and the A7704 acquisition unit. The Display unit provides results of signal acquisition, both real time and as stored in the P7001. It does this by a visual interface with the DPO in the form of an Oscilloscope. Additionally, the CRT readout is carried over into the DPO to provide appropriate scaling on the displays.

The A7704 acquisition unit, through its modular plug-ins, provides the means to acquire the analog signal.

The plug-in units used in the TDRL are the S-6 Sampling Head and the S-53 Trigger Recognizer, inserted into a 7S12 TDR/Sampler.

The 7S12 provides for measurement of recurring fast-rise time signals; i.e., the source pulse and the target back-scatter. It features the means of determining vertical deflection factors in millivolts; horizontal sweep factors in seconds; a HIGH RESOLUTION switch which reduces the waveform noise and jitter by signal averaging (10 averages per sample point); a TIME-DISTANCE scale which allows one-way distance measurements in air dielectrics; and a locate switch which increases the time/division and intensifies a portion of the display to locate the time window relative to the total waveform. Finally, the 7S12 provides the means for the inserting and interfacing of the plug-in heads into the DPO.

The S-6 Sampling Head is a 50-ohm loop through input sampling unit. It provides the means of inputting the signal of interest to the DPO. This unit has a specified rise time of 30 picoseconds or less and a bandwidth equivalent to dc to 11.5 GHz at 3 dB down. It has a signal range of +1volt to -1volt (dc to ac peak) or 1volt peak-to-peak. The S-6 establishes the baseline measuring capabilities of the TDRL.

The S-53 Trigger Recognizer permits use of the 7S12 as a general purpose sampler. It produces a stable trigger signal from input signals from DC to 1 GHz. It is capable of recognizing signals having amplitudes ranging from 10 millivolts to 2 volts peak-to-peak into 50 ohms. A trigger pulse from the pulse generator is fed into this unit at the same rate as the source signal. Trigger to signal delay is specified as 15 nanoseconds or less.

The second element of the DPO, the P7001 Processor, provides the link from the DPO to the mini-computer. This unit receives the analog signal acquired from the Acquisition unit and digitizes and stores or discards the information, along with appropriate scale factors, as selected by the operator. The method used by the digitizer is pseudo-random sampling with one sample taken every 6.5 microseconds. This is the maximum rate of sampling. Any transient longer than 5 milliseconds or COHERENTLY REPETITIVE signal up to the frequency limit specified by the Sampling Head that can be displayed on the D7704 Display Unit can be stored in internal memory along with its scale factors. The information stored can then be redisplayed on the CRT and/or sent to the minicomputer for processing. There are a maximum of 512 samples taken horzontally (9-bit word) per waveform. Although either X- or T- (TIME) may be specified for this axis, the TDRL primarily employs the time axis. Vertical resolution of the Processor is 1024 levels (10-bit word). This axis is used to measure the voltage of the back-scattered signal.

b. Tektronix 4052 Mini-Computer

The minicomputer used in the TDRL is a Tektronix 4052. It is a high performance, integrated graphics system employing LSI, bi-polar, 16-bit technology. The unit has a 64k-byte memory with a 300k-byte magnetic cartridge built in. Extended BASIC is the high level programming language employed to perform processing functions. Although this unit has many features worthy of note, the above are the salient ones for the TDRL.

c. Hard Copier

The Hard Copier used is the Tektronix 4631 Hard Copy Unit. It provides permanent, dry copies of the graphic and alphanumeric information displayed on the CRT storage screen of the 4052 mini-computer.

All units described for the Signal Processing Group were especially selected to perform as an integrated system requiring minimum interfacing. The GPIB bus is the means of transferring information from one unit to the other in the TDRL.

III. THEORY

This chapter is devoted to the general derivation of the equations which are applicable to the time-domain analysis of the impulse and ramp responses of axisymmetric, metallic bodies which are illuminated by an axially directed incident electromagnetic field. Where sources providing detailed derivations are numerous and/or adequate, the derivations in this chapter will be general, providing only the major results of interest with specific constraints noted.

The time-domain integral equations which provide solutions for the transient electromagnetic problem will be considered first. They will be followed by a discussion of the measurement equations and procedures employed in the TDRL. Finally, various methods used to reduce the noise error in acquired signals will be discussed.

A. TIME-DOMAIN INTEGRAL EQUATIONS

One primary problem in transient analysis of target impulse responses is to determine the shape of an unknown object when the incident field and the response of the scatterer to that field are a priori information. Numerous time-domain techniques have been developed which perform this function. As noted in Chapter I, the earliest method used involved the physical optics response of a body to an incident electromagnetic field. The surface currents produced an approximate impulse response that was essentially the second derivative of the projected area function of the scatterer. [Ref. 5] However, this approach was limited in its accuracy in that the relationship between the impulse response and the derivatives is exact only at the leading edge of the scattered field response, a single point in time. Interactions between currents on the target body which continue to radiate for a significant time after the incident field leading edge has propagated further in space alters the backscattered response of the target. Therefore, for an accurate solution to the problem, these additional currents must be of consideration.

Bennett [Ref. 14] first proposed a direct method which "corrected" the response by computing the currents flowing on the scatterer surface. From these currents, the scattered field could be calculated "exactly".

In general, the remainder of this section follows the format of the method used by Bennett in the derivation of integral equations for exact solutions.

1. Exact Integral Solution

The expression for the magnetic field H at an arbitrary point in space (not on the scatterer surface) is given by:

$$\vec{H}(\vec{r},t) = \vec{H}^i(\vec{r},t) + \frac{1}{4\pi} \int_s \{[\frac{1}{R^2} + \frac{1}{R}\frac{\partial}{\partial\tau}] \vec{J}(r',\tau) \times \hat{a}_R \; ds' \quad (3.1)$$

where: $\vec{H}(\vec{r},t)$ = total magnetic field at (r,t)

$\vec{H}^i(\vec{r},t)$ = incident magnetic field at (r,t)

$\vec{J}(r',t)$ = surface current at $(\vec{r}',t)$

$\vec{r}$ = position vector to the observation point

$\vec{r}'$ = position vector to the integration point

$R = |\vec{r}-\vec{r}'|$

$\hat{a}_R = \frac{\vec{r}-r'}{R}$

t = time in light-meters (one light-meter is the time it takes light to travel one meter)

τ = t-R = retarded time

By specializing the arbitrary space point to $\vec{r}$, a point on the surface of the scatterer, and then applying the boundary conditions (i.e., by causuality, incident field is zero prior to arrival of the incident pulse at a sample point), an integral equation for the current density on the surface of the scatterer can be found:

$$\vec{J}(\vec{r},t) = 2\hat{a}_n \times H^i(\vec{r},t) + \frac{1}{2\pi} \int_s \hat{a}_n \times \{[\frac{1}{R^2} + \frac{1}{R}\frac{\partial}{\partial\tau}]\ \hat{J}(\vec{r},\tau)$$

$$\times\ \hat{a}_R\}\ ds' \tag{3.2}$$

where: $\vec{r}$ = position vector to a point located on the surface of the scatterer

$\hat{a}_n$ = unit vector normal to the surface

The first term on the right-hand side of equation (3.2) is the source term. It represents the direct influence of the incident field on the current at the observation point $(\vec{r},t)$. It is the physical optics approximation for the surface current when applied to the illuminated side of the scatterer. The integral on the right side of equation (3.2) represents the influence of currents at other surface points on the current at $(\vec{r},t)$. Note that the influence of other currents on the current at $(\vec{r},t)$ is delayed by R. This allows the surface current density equation to be solved by an iterative numerical procedure in the time-domain, rather than the familiar frequency-domain matrix inversion process.

Once the surface currents have been found, the far-scattered field can be calculated by using:

$$r_o H^s(\vec{r},\tau) = \frac{1}{4\pi} \frac{\partial}{\partial\tau} \int \{\vec{J}\ (\vec{r}',\tau) \times \hat{a}_r\} \, ds' \qquad (3.3)$$

where: r_o = distance to the far-field observer

$\hat{a}_r$ = unit vector from the integration point to the far-field observer

With the substitution of the surface current expression into the above equation, and the assumption that the incident field is a ramp, the result for the backscatter direction is:

$$r_o H^s_R(\vec{r},t) = \frac{1}{2\pi} S(t_s)\hat{a}_H + \frac{1}{4\pi} \frac{\partial}{\partial\tau} \int_s \{\vec{J}_{CR}(\vec{r}',\tau) \times \hat{a}_r\} \, ds' \qquad (3.4)$$

where: $r_o \vec{H}^s_R$ = backscatter ramp response of the target

$s(t_s)$ = physical optics silhouette area of the target

r_o = distance of the far-field observer from the origin

$t = t_s + r_o$

$\hat{a}_H = \dfrac{\vec{H}^i}{|H^i|}$

$\vec{J}_{CR} = \vec{J}_c$, correction currents resulting from the incident ramp waveform.

This result provides the exact relationship between the target response and target geometry. A particular unknown sample value at a given point in space and time is determined by the exciting field at that same space-time point and by the scattered fields from earlier, more distant locations. Note that the interactions between unknown samples are displaced in time by an amount equal to the time required for a field to propagate between the samples at the speed of light. The unknown samples can be solved at any time step, provided all sample values at earlier times are already known. Thus, by determining the unknown samples, i.e., the correction currents $\vec{J}_c$, and adding the contribution of the target area function, $s(t_s)$, the target ramp response can be utilized to recover information olving the unknown dimensions.

2. Inverse Scattering Solution

The targets employed in the TDRL are all rotationally symmetric scatterers, similar to the one diagramed in Figure 3.1. The general constraints applicable to the problem are that the scatterer is symmetric about the z-axis, the incident field is axially incident, and the far-field is computed in the backscatter direction.

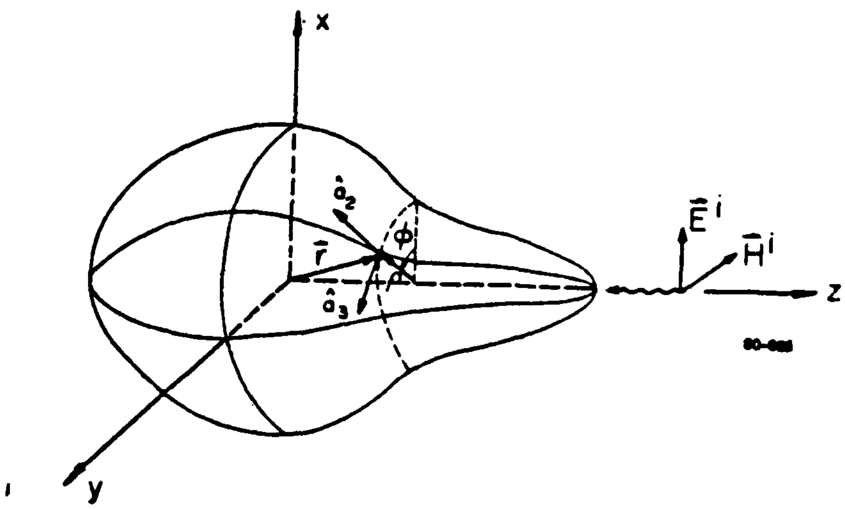


Figure 3.1. Geometry of Rotationally Symmetric Scattering Problem

The contour of a rotationally symmetric target is completely described by the radius vector $\rho(z)$ which varies as a function of z. The projected area function in the plane orthogonal to the direction of the propagation of the field (z-axis) can be expressed simply as:

$$S = \pi\rho^2(z)$$

Substituting the projected area function into the equation for the backscatter ramp response of the target and solving for (z), an inversion equation for the rotationallly symmetric case is obtained:

$$\rho(z) = [2r_o\vec{H}_R^S(\vec{r},t) - \frac{1}{2\pi}\frac{\partial}{\partial\tau}\int_S \{\vec{J}_{CR}(r',\tau) \times a_r\} \, ds'] \cdot \hat{a}_H\}^{1/2} \quad (3.5)$$

Thus, $\rho(z)$ is given in terms of the measured ramp response (a field measurement), and in terms of correction currents at earlier times, which have been previously computed or are known to be zero.

In the TDRL, an iterative approach is employed using estimates of the entire target geometry to solve for the contour function. The procedure involves five steps:

1. Neglecting the surface integral providing the correction currents, obtain the physical optics estimate of $\rho(z)$.

2. Determine the correction currents using the numerical solution of equation (3.2) for surface current density.

3. Apply the correction currents to equation (3.5) to obtain a next estimate of $\rho(z)$.

$$\rho_1(z) = [2r_o\ H_R^S\ (\vec{r},t)]^{1/2}$$

4. Compare the new value $\rho_2(z)$ with $\rho_1(z)$ to see if the change is less than some small number, an error factor. The normalized mean square error is defined as:

$$\epsilon_K^2 = \frac{(H_R^S(t) - H_{R_{k-1}}^S(t))^2}{(H_R^S(t))^2}$$

where: ε_K^2 = the value to be minimized in order to obtain the most accurate shape description

$H_{R_{k-1}}^S(t)$ = the kth estimation of the backscattered field.

Thus, the difference between the estimated and actual backscattered fields are directly linked to the difference between successive contour functions, and, therefore, successive shapes of the body.

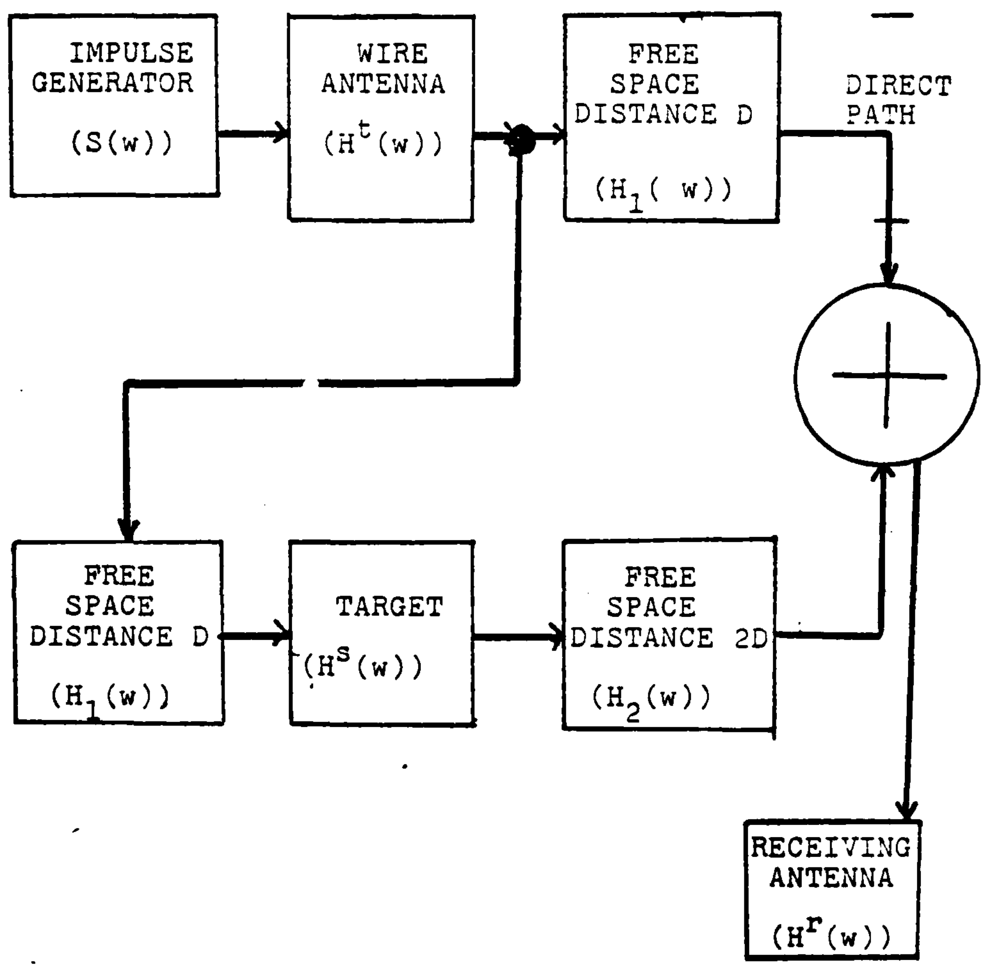
5. Repeat the iteration process until a minimum error is obtained.

The above procedure was used successfully by Morag [Ref. 15] in the development of an algorithm involving theoretical analysis of targets. This algorithm has been integrated with the overall TDRL algorithm for inverse scattering.

B. BACKSCATTERED WAVEFORM MEASUREMENTS

The TDRL algorithm is designed to minimize the effects of the impulse responses of the transmitting and receiving antennas. Figure 3.2 diagrams the parameters involved.

As can be seen, there are two measurement paths of interest. The first is the Direct Path between the transmitting and receiving antenna. The only factors affecting the transmitte waveform are the intervening distance and the impulse responses of the receiving and transmitting antennas to the source pulse. The second path is the Augmented Path, from the transmitting antenna to the target and back to receiving antenna. Factors effecting the transmitted pulse in this path include the antenna impulse



NOTE: Effects of wire transmitting antenna reflections at receiving antenna considered small -- neglected.

Figure 3.2. Signal Parameters for TDRL Measurements

responses, the impulse response of the target and the corresponding intervening distances.

Three waveforms are measured: the Direct Waveform, the Incident Waveform and the Augmented Waveform. During the measurements, $h^1(t)$ and $h^2(t)$, responses due to the delays of the intervening distances, are windowed out by using the time-range gating feature of the DPO.

The Direct Waveform is measured first. The transmitting and receiving antennas are boresighted. No target is on the imaging plane. The measured wave is then the convolved responses of the source, and transmitting and receiving antenna impulse responses. By using the properties of convolution, the frequency domain representation converts the convolution process into a product. The frequency domain representation of the Direct Waveform is:

$$A(e^{j\omega}) = S(e^{j\omega})H^t(e^{j\omega})H^r(e^{j\omega})$$

where: $A(e^{j\omega})$ = Direct Waveform

$S(e^{j\omega})$ = source pulse

$H^t(e^{j\omega})$ = transmitting antenna response

$H^r(e^{j\omega})$ = receiving antenna response

The effects of the intervening distance have been time gated out. Figure 3.3 is a representative Direct Waveform measured in the TDRL.

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         1  8-11-81  1.27M  1   1    CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............  +289.21 mV

MINIMUM PEAK VALUE............   -96.55 mV

RMS VALUE.....................   +90.58 mV

MEAN VALUE....................     0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0.5
```

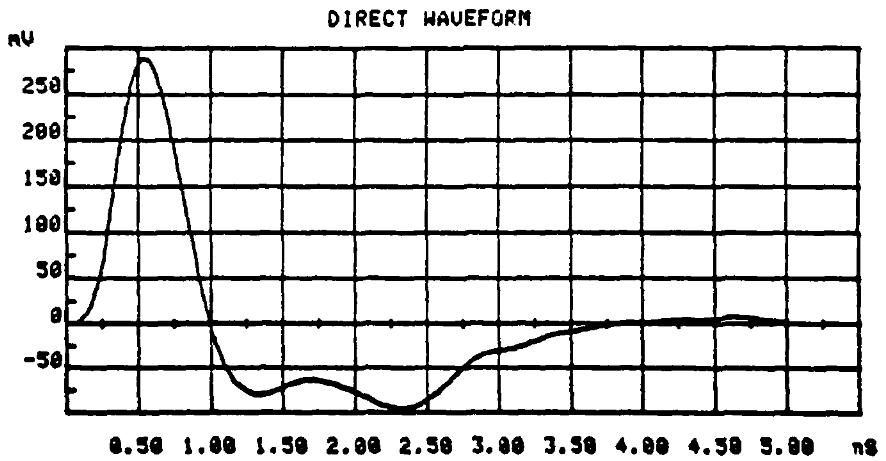


Figure 3.3. Typical Direct Waveform--Cylinder

The Incident Waveform is measured next. The imaging plane is as set-up for the Direct Waveform, but the time-gating is further delayed by $d\Delta t$ to eliminate the effects of the distance intervening between the receiving antenna and the target site. The resulting measured waveform is the Direct Waveform delayed by $d\Delta t$:

$$B(e^{j\omega}) = A(e^{j\omega})\ e^{(j\omega d\Delta t)}$$

where: $B(e^{j\omega})$ = Incident Waveform

Figure 3.4 provides a representative time-domain Incident Waveform measured in the TDRL.

The final waveform measured is the Augmented Waveform. It is a convolution of the Direct Waveform with the impulse response of the target and summed with the Incident Waveform. For this measurement, the transmitting and receiving antenna remain boresighted. A target is placed on the image plane. The measured frequency domain representation is:

$$C(e^{j\omega}) = [B(e^{j\omega}) + A(e^{j\omega})\ H^S(e^{j\omega})]e^{j\omega d\Delta t} \qquad (3.6)$$

where: $C(e^{j\omega})$ = Augmented Waveform

$H\ (e^{j\omega})$ = Target Response

Figure 3.5 provides a representative time-domain Augmented Waveform measured in the TDRL for a axisymmetric half-cylinder.

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	1	8-11-81	1.27M	1	1	CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ +4.40 mV

MINIMUM PEAK VALUE............ -3.83 mV

RMS VALUE..................... +1.92 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21   OPTIMIZATION VALUE = 0.5

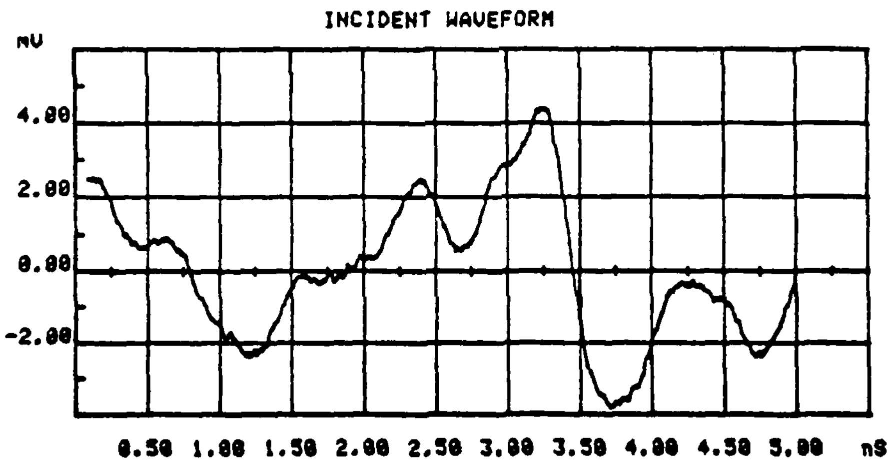


Figure 3.4. Typical Incident Waveform--Cylinder

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	1	8-11-81	1.27M	1	1	CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ +4.88 mV

MINIMUM PEAK VALUE............ -6.76 mV

RMS VALUE..................... +2.76 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

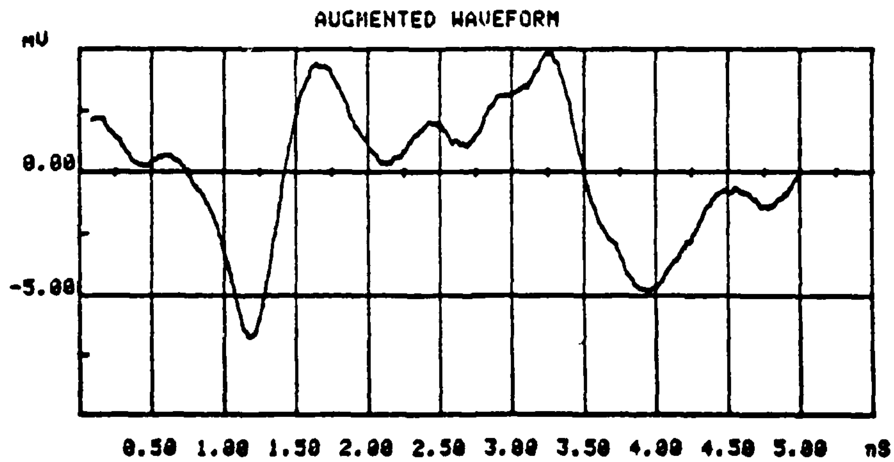


Figure 3.5. Typical Augmented Waveform--Cylinder

As can be seen from equation (3.6), the target response is not independant of the effects of the impulse responses of the antennas. To eliminate this dependance, the backscattered waveform is determined and then the remaining antenna terms are theoretically eliminated by a division process.

The Backscattered Waveform is the difference of the Augmented and the Incident Waveforms:

$$D(e^{j\omega}) = C(e^{j\omega}) - B(e^{j\omega})$$
$$= A(e^{j\omega})\, H^S(e^{j\omega})$$

Figure 3.6 is the time-domain Backscattered waveform resulting from the subtraction of the waveforms in Figures 3.5 and 3.4 respectively.

By next dividing the Backscattered Wave by the Direct Wave, all antenna influences are eliminated:

$$H^S(e^{j\omega}) = \frac{D(e^{j\omega})}{A(e^{j\omega})}$$

The target impulse response, $h^S(t)$, may now be determined by deconvolution of the target impulse frequency domain values. Figure 3.7 is a representative time-domain target impulse response for a cylinder. Noise errors have been minimized by an adaptive filtering method to be described shortly.

```
TARGET: RUN DATE      DIST   ANT TGT  REMARKS
         1  8-11-81   1.27M   1   1   CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE...........     +4.65 mV

MINIMUM PEAK VALUE...........     -4.44 mV

RMS VALUE....................     +1.71 mV

MEAN VALUE...................      0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0.5
```

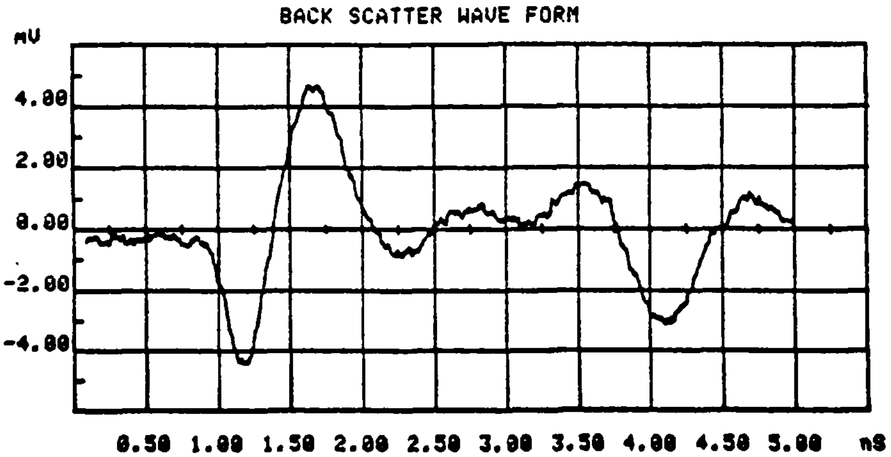


Figure 3.6. Typical Backscattered Waveform--Cylinder

```
TARGET: RUN DATE      DIST   ANT TGT  REMARKS
         1  8-11-81  1.27M   1   1    TYPICAL CYLINDER RESPONSES

   MAXIMUM PEAK VALUE............  0.0004 mV

   MINIMUM PEAK VALUE............ -0.0004 mV

   RMS VALUE.....................  0.0002 mV

   MEAN VALUE....................  0.0000 mV
NUMBER OF WAVEFORMS AVERAGED = 1      OPTIMIZATION VALUE = 10
```

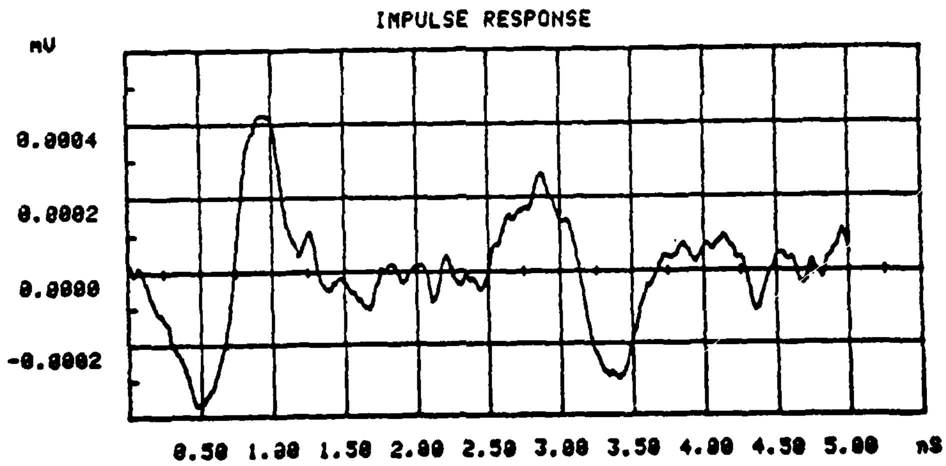


Figure 3.7. Typical Target Impulse Response With Noise Filtering--Cylinder

C. NOISE CONSIDERATONS

As noted in the previous section, deconvolution of the target backscattered impulse response, less the impulse responses of the antennas, is a central operation to the effective use of the TDRL. The reliability of the acquired signal to be a true response of a target to an incident field bears directly on the accuracy of the final results as determined by solution of the inverse integral equations for time-domain analysis. Any errors in the data representing the Incident Waveform and Augmented Waveform degrade the cancellation of the division process and introduce errors in the backscattered target response. Also present at the input to the DPO is noise due to thermal electron excitation in the transmission lines and antenna surfaces as well a that due to external atmospheric, cosmic and man-made noise sources being received by the horn antenna. When the backscattered impulse response is transformed to the time-domain, high frequency noise in most cases forms the dominant feature of the waveform. An example of a typical impulse response of a cylinder is given in Figure 3.8. Noise errors have not been removed. Figure 3.9 is the ramp response for the same target.

TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
1	8-11-81	1.27M	1	1	TYPICAL CYLINDER RESPONSES

MAXIMUM PEAK VALUE............ 0.0324 mV

MINIMUM PEAK VALUE............ -0.0314 mV

RMS VALUE..................... 0.0126 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 1   OPTIMIZATION VALUE = 0

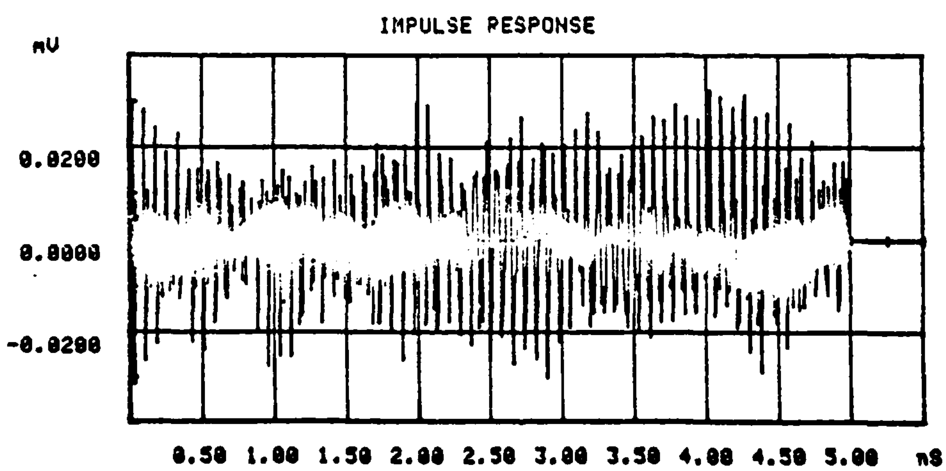


Figure 3.8. Impulse Response--Noisy Signal

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         1  8-11-81  1.27M  1   1    TYPICAL CYLINDER RESPONSES

MAXIMUM PEAK VALUE............   +53.66 mV-M

MINIMUM PEAK VALUE............  -700.00 mV-M

RMS VALUE.....................  +373.03 mV-M

MEAN VALUE....................  -285.42 mV-M

NUMBER OF WAVEFORMS AVERAGED = 1      OPTIMIZATION VALUE = 0
```

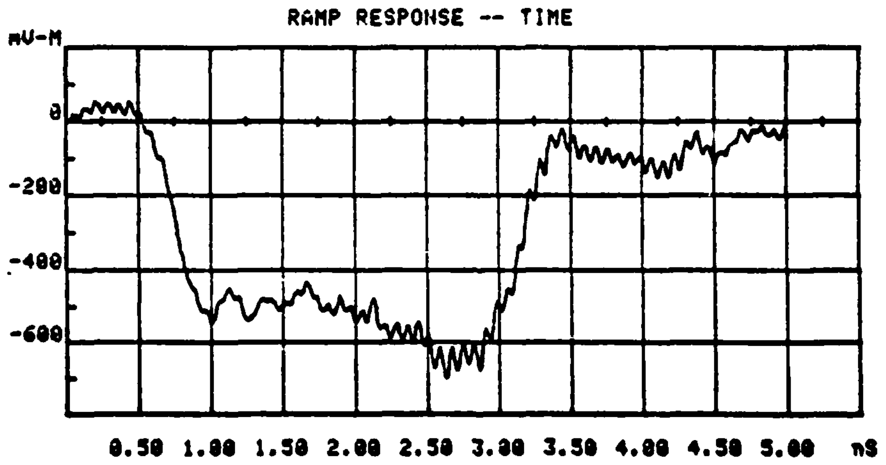


Figure 3.9. Ramp Response--Noisy Signal

In the TDRL, typical sources of errors in the Incident and Augmented Waveforms are sampling errors and noise in signal acquisition, leakage and aliasing errors in the Fourier Transfomations, and rounding errors in the computer. The error of primary concern is that involving noise in signal acquisition and in particular the enhanced high-frequency noise resulting from deconvolution of the antenna responses to obtain the impulse and ramp responses of the target. This noise has been directly traced to the structure of the data within the input array, as will be noted in Chapter IV.

Two methods are employed to reduce noise to acceptable levels: acquisition averaging and an optimal compensation technique. [Ref. 16]

1. Acquisition Averaging

Acquisition averaging is aimed at reducing signal acquisition errors and noise by averaging several acquisitions taken within a short period of time. During the process, a more serious error may be generated, that due to signal drift with time. Signal averaging has been most useful in ensuring a good target ramp response. It has had noticeable effect on making the information content of the impulse response more available. Figure 3.10 demonstrates an impulse waveform with 210 acquisitions for the same target as for Figure 3.8. Theoretically, the RMS noise level should be reduced by the square root of the number of acquisitions, N. N = 10 in Figure 3.8, and N = 210 in Figure 3.10. The noise reduction should be about 4.5 times. Note that the noise level in Figure 3.10 is indeed about one fourth that in 3.8.

Figure 3.11 is the corresponding ramp response. Signal acquisition only is employed.

2. Optimal Compensation Technique

The optimal compensation technique involves the design of a compensator (deconvolution) function operating on the convolution output of the Incident and Backscattered Waveforms, to produce a relatively noise-free estimated Impulse Response for the target. The compensator is applied to the convolution product of the target impulse response and the Direct Waveform to produce the required deconvolution result. The design as used in the TDRL involves an iteration process on a single variable with a "man-in-the-loop" to determine optimal values of the variable.

Figure 3.12 diagrams the design of a frequency domain optimal compensator. The compensation principal in

TARGET: RUN DATE DIST ANT TGT REMARKS

TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
1	8-11-81	1.27M	1	1	CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ 0.0094 mV

MINIMUM PEAK VALUE............ -0.0091 mV

RMS VALUE..................... 0.0033 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

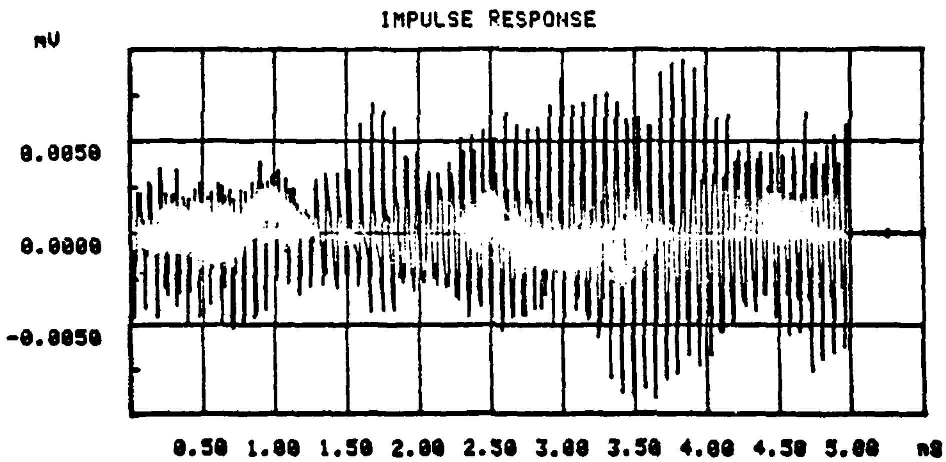


Figure 3.10. Impulse Response: No Optimization--Acquistion Averaged

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         4  8-11-81  1.27M  1   1    CYLINDER-ACQUISITION AVG

MAXIMUM PEAK VALUE...........   +82.97 mV-M

MINIMUM PEAK VALUE...........  -441.33 mV-M

RMS VALUE....................  +253.42 mV-M

MEAN VALUE...................  -178.46 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
```

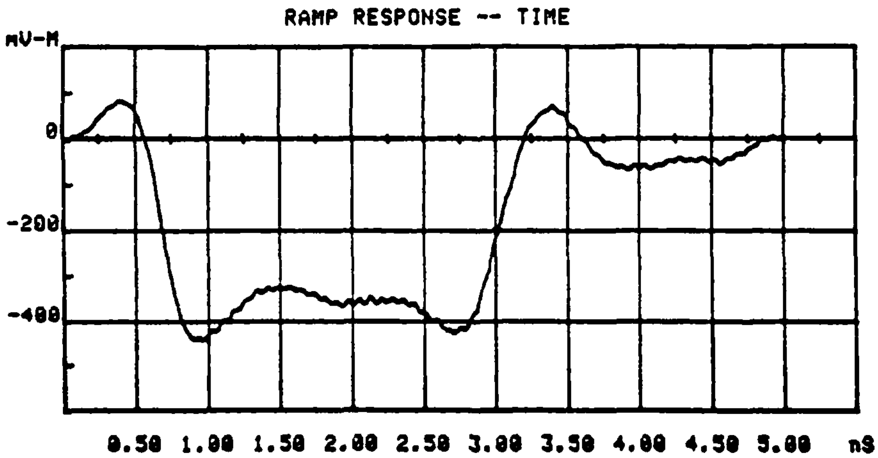


Figure 3.11. Ramp Response: No Optimization--Acquistion Averaged

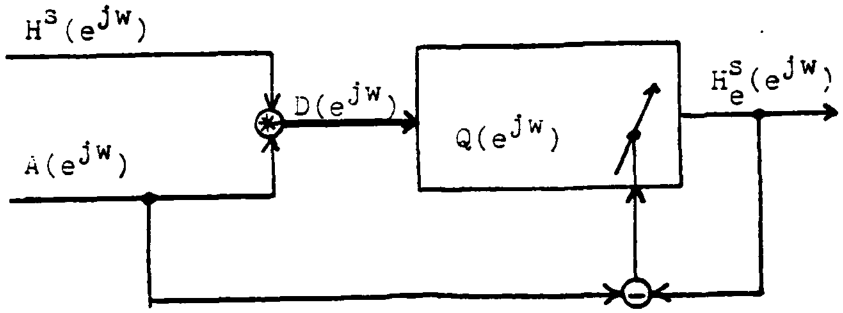


Figure 3.12. Frequency Domain Optimal Compensator Design

deconvolution is to design a transfer function $Q(e^{j\omega})$ to be applied to the backscatter response $D(e^{j\omega})$ to yield an estimate of the target impulse response $H_e^s(e^{j\omega})$. That is:

$$H_e^S(e^{j\omega}) = D(e^{j\omega})Q(e^{j\omega}) \tag{3.7a}$$

$$= A(e^{j\omega})H^S(e^{j\omega})Q(e^{j\omega}) \tag{3.7b}$$

The main design criteria is to minimize the energy in the noise terms that introduce error in the estimate. The error energy, E is given by:

$$E_e = \int_0^{\Omega} | H_e^S (e^{j\omega}) - H^S (e^{j\omega}) |^2 d\omega \tag{3.8}$$

where: Ω = frequency band of interest.

When the error energy is minimized, $H_e^s(e^{j\omega})$ will equal $H^s(e^{j\omega})$ and the impulse responses will be identical, except for the addition of highly enhanced random noise. In this case, the compensator transfer function is:

$$Q(e^{j\omega}) = \frac{1}{A(e^{j\omega})} \quad , \quad H_e^S(e^{j\omega}) = H^S(e^{j\omega}) \tag{3.9}$$

But, this will result in an infinite, unbounded value for $Q(e^{j\omega})$ as $A(e^{j\omega})$ goes to zero, yielding a noisy form for $H^S(e^{j\omega})$. This noise can be limited by constraining $Q(e\quad)$ to be a bounded function. Noting that the impulse response of the target is bounded by physical constraints, it is possible to keep the energy due to the convolution of the impulse response and the designed transfer function bounded, i.e.:

$$E_c = \int_0^{\Omega} \left| H(e^{j\omega})\, Q(e^{j\omega}) \right|^2 d\omega \tag{3.10}$$

The problem now is to minimize E while keeping E finite. The total energy in the backscattered wave can be defined as:

$$E = E_c + \lambda E_c \ , \quad \lambda \geq 0 \tag{3.11a}$$

$$= \int_0^{\Omega} [\,| H_e^S(e^{j\omega}) - H^S(e^{j\omega}) |^2 + \lambda\, |H(e^{j\omega})Q(e^{j\omega})|^2]\, d\omega \tag{3.11b}$$

where: λ = optimization parameter.

Thus, by minimizing the total error energy through the selection of the optimal value of λ, the error energy in the estimate is also minimized. The result yields an optimum compensator $Q_{opt}(e^{j\omega})$ for the unknown target impulse response $h^{s}(t)$. The result is that the whole system output is low-pass filtered with minimal effect on waveform shape.

Adhering to the design constraints listed above, it can be shown that the form of the compensating transfer function $Q(e^{j\omega})$ for a given Direct Waveform $A(e^{j\omega})$ is: [Ref. 17]

$$Q(e^{j\omega}) = \frac{A^*(e^{j\omega})}{[|A(e^{j\omega})|^2+\lambda]} \tag{3.12}$$

where: $A^*(e^{j\omega})$ = complex conjugate

From equation 3.7, the compensation deconvolution process yields:

$$H_e^S = \frac{D(e^{j\omega})A^*(e^{j\omega})}{[|A(e^{j\omega})|^2+\lambda]} \tag{3.13}$$

Figure 3.13 shows the effect that optimization has on the impulse response with no sgnal acquisition averaging. Optimization is 0.5. The target impulse response, while

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 TYPICAL CYLINDER RESPONSES

MAXIMUM PEAK VALUE............ 0.0011 mV

MINIMUM PEAK VALUE............ -0.0010 mV

RMS VALUE..................... 0.0004 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0.5

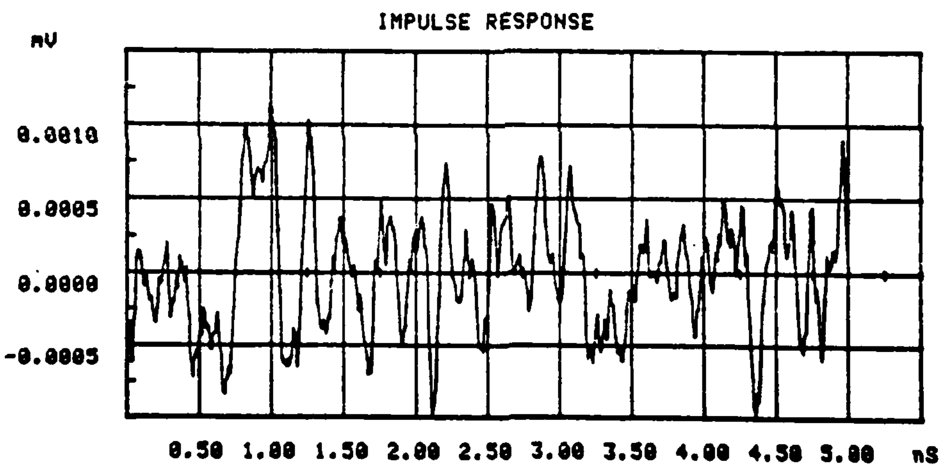


Figure 3.13. Impulse Response: .5 Optimization---
No Acquisition Averaging

still noisy, is clearly discernable. Figure 3.13 should be compared with Figure 3.11. Figure 3.14 shows the effect of optimization increased to 10. The noise is almost totally eliminated. The trade-off is that the optimization has reduced the amplitude of the response and spread it in frequency. This is a general observation. However, it appears that the degree of effect on the waveform is a function of the ideal optimization factor. Chapter V will explore this concept more fully. However, it should be noted that if the optimization factor is large enough to reduce the large scale features of the target then it is too large and should be reduced--this is the "man in the loop's" job.

The combination of waveform averaging and optimization on the impulse response is demonstrated in Figures 3.15 and 3.16. With a relatively small amount of optimization, the target impulse response is readily apparent. See Figure 3.16. Signal acquisition averaging also yields an important advantage. Since noise is reduced directly by the square root of the number of acquisitions, and because no filtering of any sort is employed for averaging alone, the detailed features of the actual signal are not eliminated as with filtering. The smaller amount of optimization needed results in minimum effect by the compensator on the shape of the output waveform. The trade-off is the increased liklihood of error introduced due to signal time drift during the acquistion averaging period.

Figures 3.17 to 3.21 show the effects of signal averaging and optimization on the Ramp Responses. Each figure is presented in the same order as were the Impulse Responses. Signal averaging is very beneficial in obtaining an accurate ramp response. Optimization has a greater tendency to effect the wave shape of the ramp response than the impulse response of the target. But less optimization is required to reduce the error noise. It is generally possible to use the ramp response without optimization. The main effect of optimization is to spread the frequency content of the ramp response. Amplitude effects are minor.

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 TYPICAL CYLINDER RESPONSES

MAXIMUM PEAK VALUE............ 0.0004 mV

MINIMUM PEAK VALUE............ -0.0004 mV

RMS VALUE..................... 0.0002 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 10

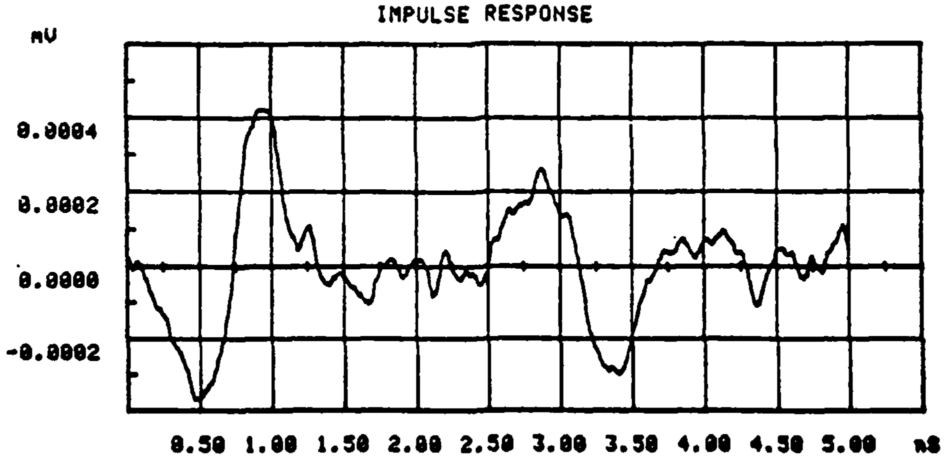


Figure 3.14. Impulse Response: 10 Optimization--No Acquisition Averaging

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         1  8-11-81  1.27M  1   1    CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............  0.0094 mV

MINIMUM PEAK VALUE............ -0.0091 mV

RMS VALUE.....................  0.0033 mV

MEAN VALUE....................  0.0000 mV
NUMBER OF WAVEFORMS AVERAGED = 21     OPTIMIZATION VALUE = 0
```

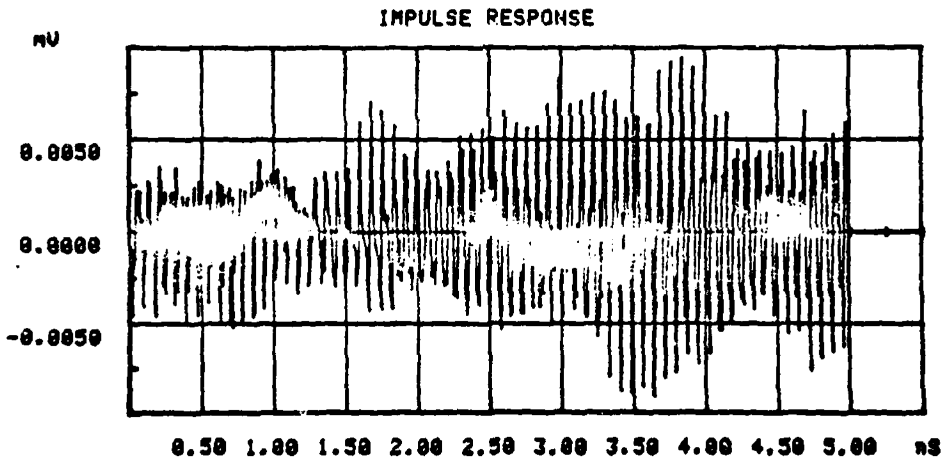


Figure 3.15. Impulse Response: No Optimization--210 Acquisitions Averaged

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ 0.0010 mV

MINIMUM PEAK VALUE............ -0.0009 mV

RMS VALUE..................... 0.0003 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

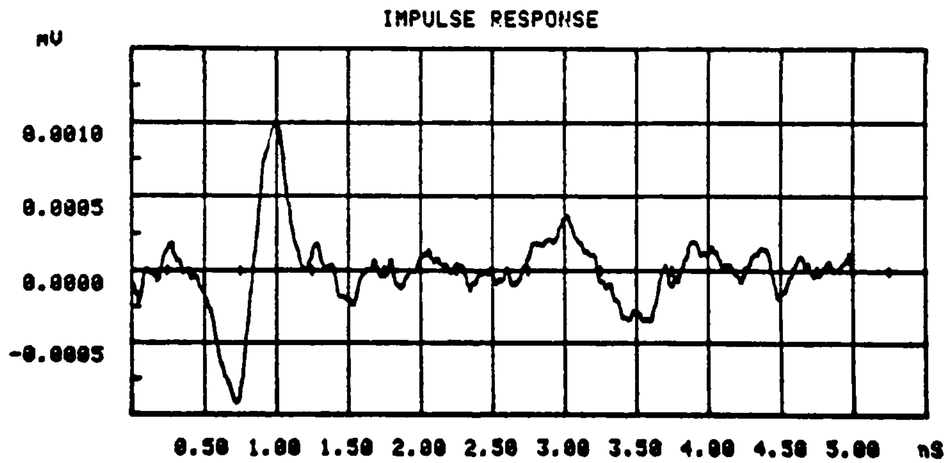


Figure 3.16. Impulse Response: .5 Optimization--210 Acquisitions Averaged

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 TYPICAL CYLINDER RESPONSES

MAXIMUM PEAK VALUE............ +53.66 mV-M

MINIMUM PEAK VALUE............ -700.00 mV-M

RMS VALUE..................... +373.03 mV-M

MEAN VALUE.................... -285.42 mV-M

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0

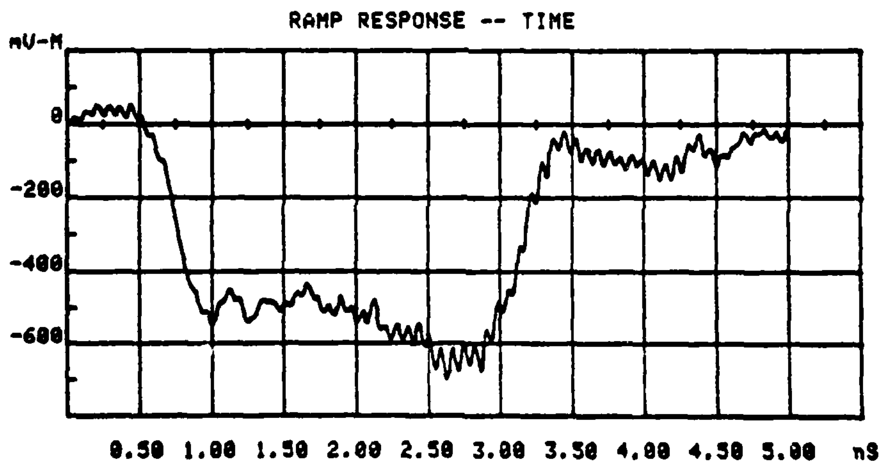


Figure 3.17. Ramp Response: No Optimization--No Acquisition Averaging

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 TYPICAL CYLINDER RESPONSES

MAXIMUM PEAK VALUE........... +47.77 mV-M

MINIMUM PEAK VALUE........... -647.48 mV-M

RMS VALUE.................... +367.11 mV-M

MEAN VALUE................... -279.80 mV-M

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 0.5

RAMP RESPONSE -- TIME

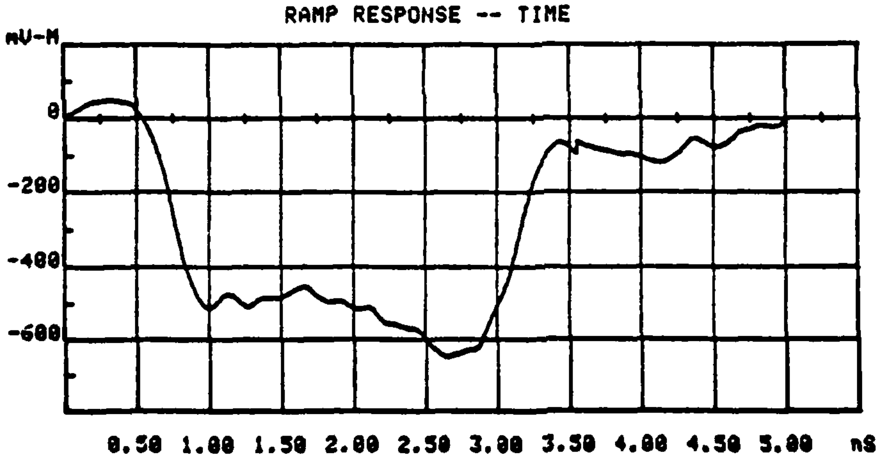


Figure 3.18. Ramp Response: .5 Optimization--No Acquisition Averaging

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ +69.81 mV-M

MINIMUM PEAK VALUE............ -401.45 mV-M

RMS VALUE..................... +231.11 mV-M

MEAN VALUE.................... -170.58 mV-M

NUMBER OF WAVEFORMS AVERAGED = 1 OPTIMIZATION VALUE = 10

RAMP RESPONSE -- TIME

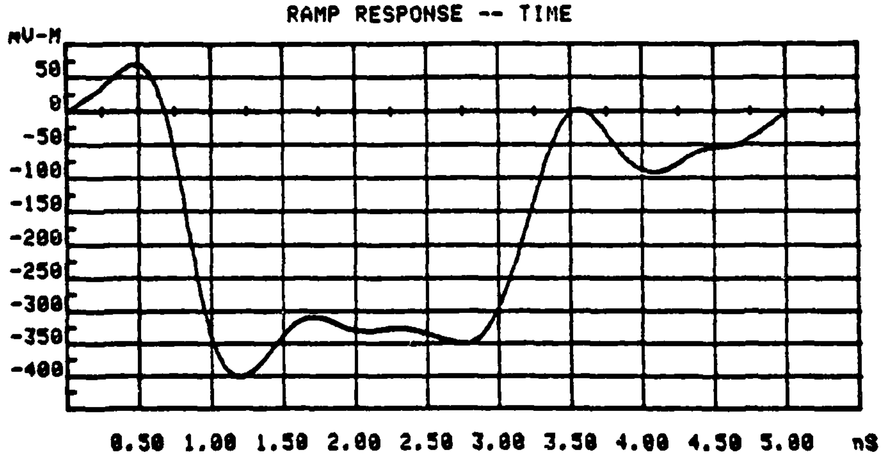


Figure 3.19. Ramp Response: 10 Optimization--No Acquisition Averaging

TARGET: RUN DATE DIST ANT TGT REMARKS
1 8-11-81 1.27M 1 1 CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ +70.58 mV-M

MINIMUM PEAK VALUE............ -467.95 mV-M

RMS VALUE...................... +289.59 mV-M

MEAN VALUE..................... -223.75 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

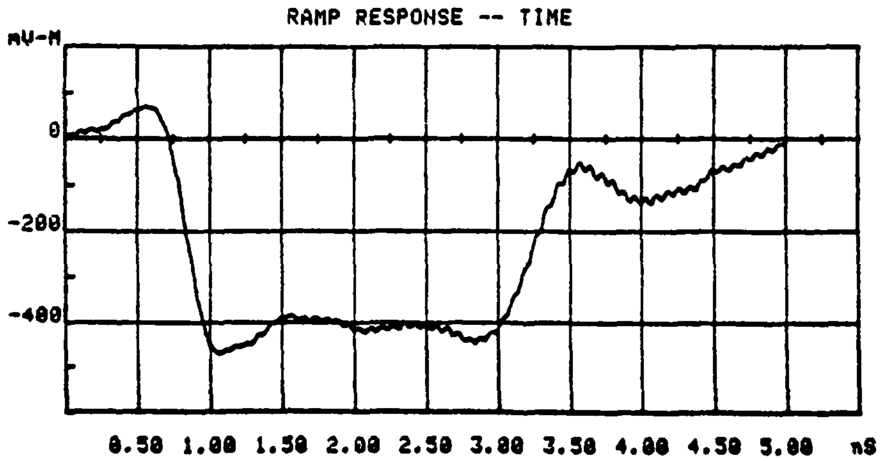


Figure 3.20. Ramp Response: No Optimization--210 Acquisitions Averaged

TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
1	9-11-81	1.27M	1	1	CYLINDER ACQUISITION AVERAGE

MAXIMUM PEAK VALUE............ +72.25 mV-M

MINIMUM PEAK VALUE............ -465.94 mV-M

RMS VALUE..................... +288.81 mV-M

MEAN VALUE.................... -222.20 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

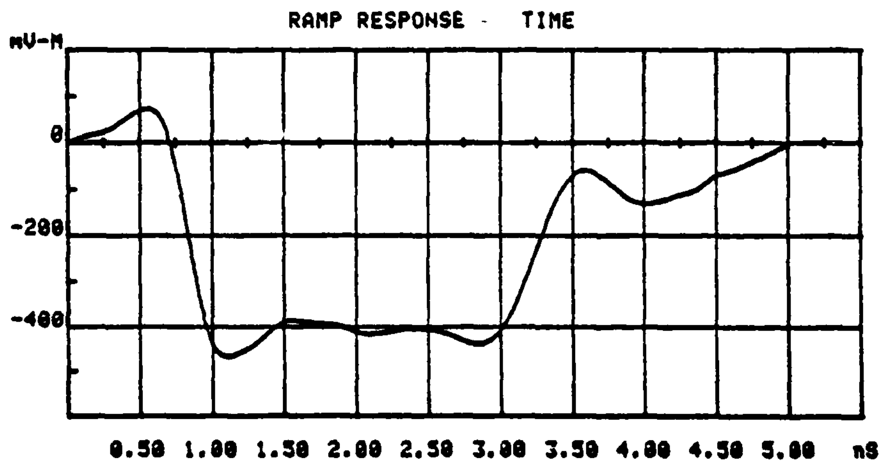


Figure 3.21. Ramp Response: .5 Optimization--210 Acquisitions Averaged

IV. OPERATING SYSTEM COMPUTER IMPLEMENTATION

A. INTRODUCTION

A set of software programs called the "Operating System" controls the input, processing and output of information obtained in the TDRL. It is the quality and throughness of the Operating System that directly determines the quality of the results obtained. In this chapter, there will be a discussion in detail of the implementation of the Operating System. It will begin by discussing the physical structure of the the host processor. A brief overview of the Operating System will follow, defining the basic sub-programs that make-up the total algorithm. Finally, a detailed description of each program will be provided, emphasizing the method of implementation of the numerical solutions, where applicable, and giving details of a procedure to run the individual programs.

B. THE TEKTRONIX 4052 GRAPHIC COMPUTING SYSTEM

The host processor used in the TDRL is the Tektronics 4052 Graphic Computing System. It is a versatile, stand alone microprocessor. As such, its capabilities and limitations are important driving functions that shape the structure of the Operating System.

The 4052 has three memories. They are:

1. Read Only Memory (ROM)--a permanent memory that contains the System's intelligence.
2. Random Access Memory (RAM)--working memory of the processor's CPU.
3. Line Buffer--small temporary memory that allows data to be written and edited on a display screen prior to releasing it to the RAM. An important editing feature.

Built-in peripherals for the Graphic System (GS) are a smart keyboard (primary input), a CRT visual display screen (primary output) and a magnetic tape unit (mass storage). Three extenal peripheral devices extend the versatility of the system. They are a Tektronix 4631 Hard Copy Unit (makes paper copies of display information), a 4924 Digital Cartridge Tape Drive (additional mass storage) and a Digital Processing Oscilloscope (data acquisition). A block diagram for the system is shown in Figure 4.1. [Ref. 18]

The Processor is the main computing device. It corresponds to the Central Processing Unit (CPU) found in larger systems. It maintains the "firmware" that allows the GS to direct system operations, decode instructions and perform arithmetic and logic operations.

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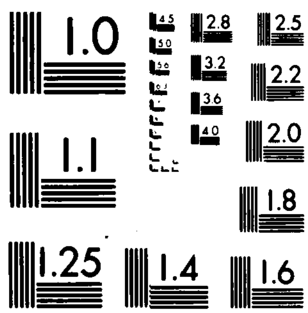

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

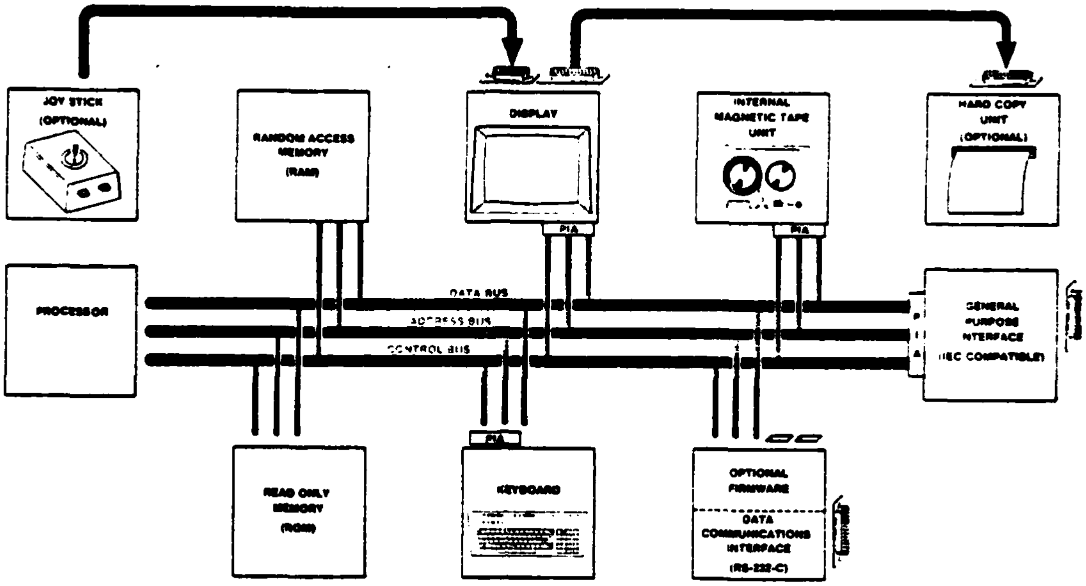


Figure 4.1. Block Diagram of TDRL Graphic System

The General Purpose Interface provides the means for the system to communicate information to or receive data from any external peripheral that is compatible with IEEE Standard 488-1975. This interface is a bit-parallel, byte-serial system capable of transfering ASCII code or machine dependant binary code up to 8-bits wide at a maximum rate of 250-k bytes/second.

A magnetic tape data cartridge is used in the internal magnetic and peripheral tape drive units to provide up to 300-k bytes of additional mass storage per tape. Programs and data may be stored on tape in specifically defined "files". Files may range in size from 768-bytes up to the limit of the magnetic tape storage capability. Files may be either ASCII or binary in format. All files in the Operating System are stored in Binary format to take advantage of a peripheral "firmware" package called the binary loader. Binary data transfers between the processor compiler and magnetic tapes are faster than when stored in ASCII. This is because the processor uses binary format for internal processing and the conversion from ASCII to binary format is eliminated when data is stored binary. Additionally, a stored binary program can be transfered to the processor memory from a specified peripheral device without disturbing variables and associated values previously defined. This feature is not available to ASCII programs.

The GS permanent ROM has been programmed to respond to BASIC (Beginner's All-Purpose Symbolic Instruction Code), a high-level programming language first developed at Dartmouth College. The Operating System has been correspondingly written in this language. However, BASIC as used by the GS has been extended to fit the language to the specialized capabilities of Graphic System. These extensions are in the areas of graphics, file system access, unified handling of input/output operations, matrices, character string manipulation, high-level language interrupt handling, and operating system facilities. A key difference between extended GS BASIC and most other BASIC languages is that most keywords and their parameters can be evaluated independantly of program control. The result is a rich, versatile, yet simple to use programming tool.

Three peripheral ROM firmware packages have been added to the TDRL system to tailor it to specific needs of the laboratory. They are the Signal Processing ROM Pack No. 1, Signal Processing ROM Pack No. 2 (FFT), and the EDITOR. A description of each is provided in Appendix A.

C. OVERVIEW OF THE TDRL OPERATING SYSTEM

The TDRL Operating System has been specifically designed to be higly operator-processor interactive. This provides the greatest degree of flexibility in the acquisition, processing and evaluation of electromagnetic time domain transients for target imaging.

The total Operating System occupies 83818-bytes of mass storage on TDRL Library Tape 1 in three files. It requires an additional 201628-bytes of storage in 62-files on TDRL Library Tape 2 (Data Storage). The Operating System is logically divided into three-individual programs:

1. INPUT--for the acquisition and averaging of signals of interest.
2. MATH--performs the significant mathmatical processing of the acquired signals for inverse scattering.
3. GRAPH--provides a visual display to the operator of the results of the processing.

TABLE III

Mass Storage TDRL Programs

PROGRAM	FILE #	BYTES	%
INPUT	2	24552	12
MATH	3	14256	7
GRAPH	4	42624	22

Mass storage requirements of the Operating System programs are given in TABLE III. The storage requirements listed in TABLE III are for the programs only and do not include requirements for the necessary definition of arrays, strings or numeric constants and variables.

All programs are designed to be as nearly independant of each other as possible, after an initial run, to allow for maximum flexibility and utility in data usage and evaluation. The most dependant program is MATH which cannot be used without inputs from either INPUT or GRAPH. The most independant program is GRAPH which is capable of being run with inputs from mass storage only.

A general flow diagram of the operating system is given in Figure 4.2. Specific named subroutines have not been shown. The next section will describe in detail the individual programs of the Operating System and their specific requirements and processing methods.

D. OPERATING SYSTEM PROGRAM DESCRIPTION

This section will describe in detail the individual programs and their subroutines that make-up the Operating System for the TDRL. A general description of the purpose of each program will be provided first. Sources of inputs and outputs will be noted. A general flow diagram for the specific program will be provided showing how all subroutines interact. This general overview will then be followed by a more detailed description of each subroutine in the program. The purpose of the subroutine will be

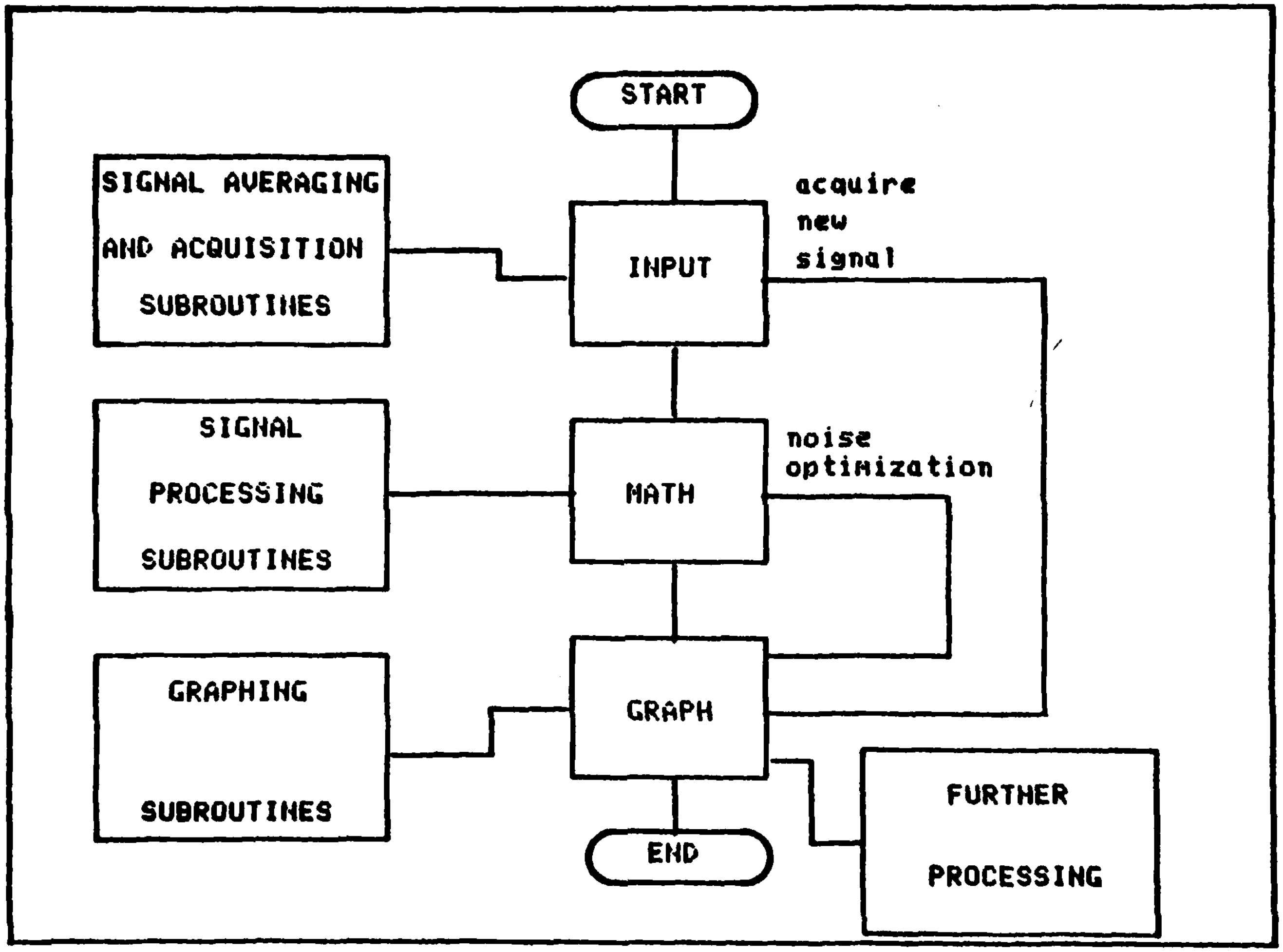


Figure 4.2. General Flow Diagram of TDRL Operating System

noted. Sources of input and output will be defined. A discussion of applicable algorithms and the flow of information will be also provided. Examples of visual displays applicable, potential problems and correction methods, will be discussed when warranted.

As noted, the following commentary will make frequent referance to program generated messages. Examples of these messages will not be given in the body of this text, but can be found in Appendix F, a general run of the Operating System.

1. Program INPUT

INPUT provides the means to initialize and drive the total Operating System. This sub-program is stored on Library Tape 1, File 2. Memory space required for its implementation in the processor CPU is 24552-bytes. With all arrays and constants defined, a total of 42469-bytes of memory space may be required. A listing of INPUT can be reviewed in Appendix C.

INPUT is the front-end program for the Operating System and as such, will generally be the first program to be initiated for TDRL measurements. Program start-up is begun by placing Tape 1 into the 4052 built-in magnetic tape drive, and placing Data Storage Tape 2 in the 4924 Remote

Tape Drive. INPUT is then normally placed into the CPU's working memory under operator control by the issue of the following commands from the keyboard:

FIND 2

CALL "BOLD"

Program execution is next begun by typing the command "RUN" from the keyboard.

If this is the first attempt to run the Operating System in conjunction with the Digital Processing Oscilloscope (it is assumed the DPO is "ON" whenever INPUT is employed), the following message may appear on the GS CRT following the issuance of "FIND 2":

"No SRQ on unit in immediate line -- message number 43."

If the program is being run from any line prior to line 140 (the usual case), this message may be ignored and the program will automatically correct the error message and continue processing. If the program is being run subsequent to line 140 (the case when returning to INPUT from some other internal file), the following command must be entered from the keyboard:

POLL N,N;1

Following this, the regular sequence of commands may then be issued to start the system.

As noted, INPUT may alternately be loaded and initiated under program control from GRAPH (File 4). Execution will begin following line 180 in this case. This return to INPUT occurs in normal Operating System (OS) operation after an initial run has been completed and information is then desired for an entirely new target.

The program specifically provides for the means to input information concerning the transient electromagnetic response of a target. It acquires, averages and stores all pertinent waveforms. INPUT also allows for the easy storage of specific antenna and target dimension parameters for comparison when the target is known exactly. This data is permanently maintained in a library on Tape 2 in Files 5-49. INPUT further initializes most of the parameters used later in Program GRAPH for the visual display of the processed results.

Data inputs are from the keyboard or internal memory. Outputs are to internal memory, mass storage and File 3 (MATH). INPUT is highly operator-processor interactive. Numerous directives and visual displays guide the user.

The structure of the program consists of 11-subroutines. One (DRIVER) is of general application to the program. Five (ACAVG, INWAV, DIWAV, AUGWAV, SCATWAV) are specifically related to input, acquisition, averaging and storage of relevant information concerning the time-domain transient response of the target in question. The remaining five subroutines (ANTLOC, TGTLOC, NEWPAR, ANTIN, TGTIN) provide special services for the operating system. A general flow diagram for input is provided in Figure 4.3 A description of each subroutine follows.

a. DRIVER

This is the main driving routine for INPUT. It consists of 129 steps (40% of the program) from line 100 through line 1260. It is initiated directly under operator control at line 100, or under program control from GRAPH in line 180. Data is input from the keyboard or from the mass storage files located on Tape 2. DRIVER will pass program control directly to MATH when directed.

Lines 100-300 initialize various variables and dimension various arrays. Line 150 clears the General Purpose Interface Bus (GPIB) of the DPO service request. Flag P7 (indicates whether the acquired data is destined for use in Time Domain or Prony Methods) is set to 0 (Time Domain) in line 160. P8, the run number, is initialized to zero in line 170 and will be incremented by one in line 210

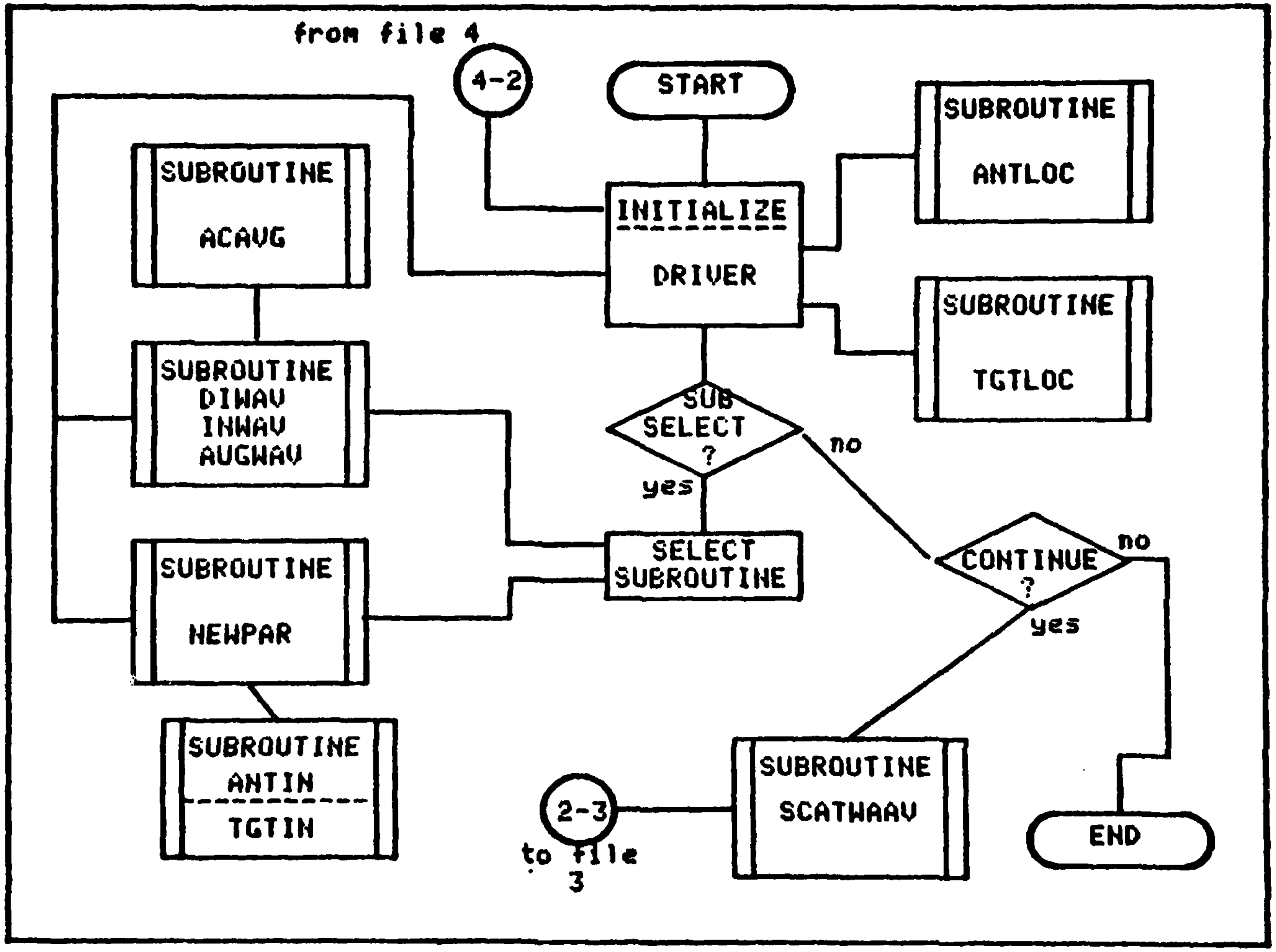


Figure 4.3. General Flow Diagram of INPUT

for every run (including the first). Various string constants are initialized in line 240-250 and 280-290. Flag P9 (indicates the need for initializing input parameters) is set to 1 (input parameters required). Lines 320-530 provide a menu of subroutines and functions which are available for Operator selection. The selection of a process from the menu is input from the keyboard into system variable P0. An example of the menu is given in Appendix F.

Lines 550-570 direct the program flow to the appropriate portion of DRIVER. If the operator has selected one of the first four subroutines, and this is an initial run of the OS, then the time for a full screen sweep of the DPO must be inputted to the program from the keyboard. The sweep rate is put in in seconds in T1 in line 640 and must be greater than or equal to the time required for the the DPO beam to sweep completely across the DPO screen.

Program control is now passed to line 850-1070 where the following run descriptive parameters are input:

1. Date
2. The distance the target is from the transmitting antenna
3. The antenna number selected
4. The target number selected

5. Explanatory remarks

These are all keyboard entries. An example of the messages that query entry of the above parameters is given in Appendix F.

If the run is not the first for the Operating System, a different series of inputs are queried. In this case, program control is passed to lines 670-840 which generate messages on the GS asking the operator if there is a change in the original location of the target, if a new antenna is to be used, or if a defined target is to be changed. The operator inputs the alpha character "Y" or "N" for "yes" or "no" from the keyboard to reflect the current situation. Appendix F displays these messages.

Lines 1000-1040 generate the input of the antenna parameters. These parameters are drawn from files stored on Data Tape 2. Each antenna file, located in one of the files numbered 5-24, is a 63-element array, returned in A5. In elements 1 through 60 are located:

1. the run number for this particular antenna-target combination
2. the antenna length compensating parameter for the antenna-target combination

3. the antenna amplitude compensator for the antenna-target combination

As can be seen, antenna parameters are actually three elements within the larger array, each three elements identifying a unique antenna-target combination. The parameters in elements 61-63 are system antenna parameters used for unknown targets. They are simply the sum of all run, antenna length compensator updates and antenna amplitude compensator updates. The average of the last two elements is applied to signals acquired if the target is not defined from the target library. This is shown in lines 1024-1025.

The antenna amplitude compensator is a very sensitive function of the distance the target is from the transmitter due to EM propagation attenuation. In line 1025, for unknown targets, and in line 4152 for defined targets, these losses are taken in consideration by finding the square of the ratio of the targets true location on the plane with referance to the transmitting antenna and the control distance (1.27m).

After the definition of variables is complete, DRIVER passes control to the appropriate function in line 1090. Line 1100 returns the display to the Menu for further function selection or to line 1170 where the DRIVER passes control to MATH and terminates any further INPUT processing.

In summary, INPUT DRIVER requires input of selected program routines and initial parameters by the operator from the keyboard, and requires the OS to determine whether the current run is the initial for the day or a subsequent one. The parameters are saved for later graph requirements. Funtion selection drives the appropriate subroutines and routines. A flow diagram for GRAPH DRIVER is provided in Figure 4.4.

b. Subroutine ANTLOC/TGTLOC

ANTLOC and TGTLOC are similiar subroutines in that they locate the appropriate antenna and target storage arrays filed on Tape 2. Antenna parameters are located in Files 5-24. Target parameters are located in files 26-45. Lines 4000-4060 contain ANTLOC. TGTLOC is found in lines 4100-4160. TGTLOC has the additional function of defining the system antenna parameters for the current run, as shown in lines 4149-4153. There are no operator-procecessor interactions during execution of these subroutines.

c. Subroutine DIWAv/INWAV/AUGWAV

DIWAV, INWAV and AUGWAV are similar subroutines. They drive ACAVG to input the direct waveform, the incident

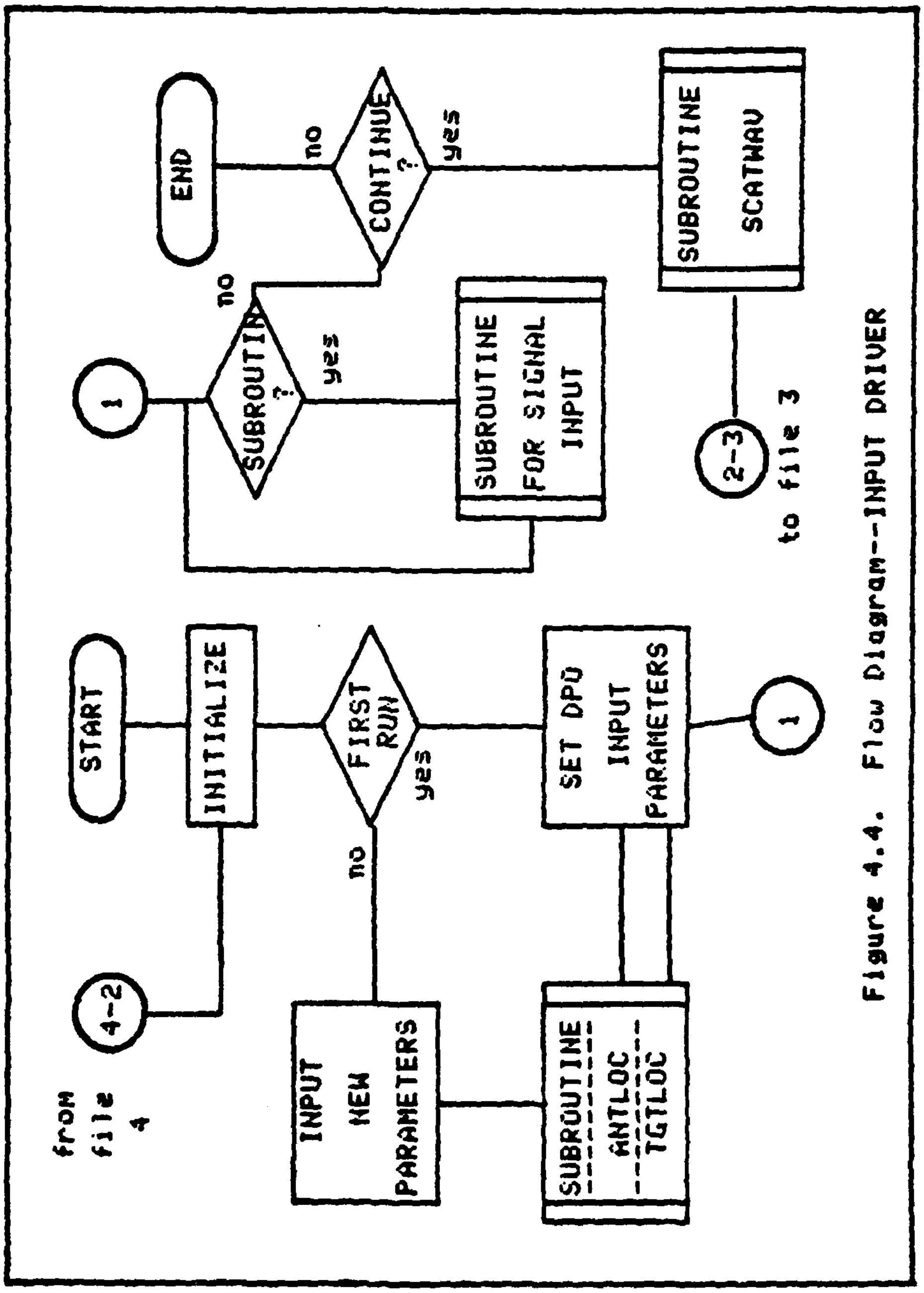


Figure 4.4. Flow Diagram--INPUT DRIVER

waveform, and the augmented waveform. They allow the selection by the Operator of the number of signals to be acquired for each waveform by the DPO (total composite waveforms from the sampler) and averaged by the OS. Each of these subroutines is accompanied by a message on CRT describing the procedure to be employed in acquiring the particular signal. These messages are reproduced in Appendix F. DIWAV is located at lines 3000-3170. It saves data in File 50 of Tape 2. INWAV is located at lines 3200-3380. It saves data in File 51. AUGWAV is located at lines 3400-3590. It saves data in File 52.

d. Subroutine ACAVG

ACAVG acquires and averages the appropriate waveform interactively requested by the operator from the processor keyboard. It also removes any dc signal that might be included in the acquisition. This feature allows the operator to position the desired signal anywhere on the DPO screen and still maintain a true zero axis in later graphic displays. Note, the signal waveform must be completely within the DPO screen area. ACAVG is 74-steps long (23% of the program) and is located in statements 2000-2730. It is driven by one of the appropriate input waveform subroutines previously described. It returns results to that subroutine for later storage. It also displays system information for the current signal being acquired to the DPO screen.

Lines 2090-2130 initialize ACAVG by requesting the operator to input the number of waveform signals to be averaged in N2. This value is then returned for verification. In lines 2140-2540, the OS writes the current acquisiton number of the waveform to the DPO screen, acquires and stores the signal into DPO memory and then transfers the signal to the 4052 for further processing.

Lines 2170-2370 perform the count function. Depending on the number of waveforms desired, the count will be for every signal (N2 less than 21), for every five signals (N2 less than 101) or for every ten signals (N2 greater than or equal to 101). This is done to reduce the time required for acquisition of all signals.

Lines 2410-2430 instruct the DPO to store and hold the waveform in DPO memory. Line 2420 stops processing to allow for the DPO to fully acquire the waveform in a single sweep. T1 is the length of the wait.

In lines 2440-2450, the GS instructs the DPO to transfer the digitized signal from DPO memory to the microprocessor temporary storage array X0. Lines 2470-2500 then search the first eight values of the array for any obviously out of range values input by poor DPO blanking on the signal front end. If such a value is found, the array element is set to discrete value 511, corresponding to a scaled value of 0. The waveform is next added to the sum of the previous waveforms for the current acquisition in line 2530. The resultant matrix is the time sampled values of the signal in B0:

$$B0 = \sum_{i=1}^{N} X0_i \qquad (4.1)$$

If further acquistions are necessary, the entire process described above is repeated. If no further acquisitons are to be done on the current signal, the ensemble average time sampling matrix X0 is determined in line 2550:

$$X0 = B0/N2 \qquad (4.2)$$

Any dc offset is eliminated in line 2560.

It is interesting to note the time required to acquire and average signals using the solid state UHF pulse generator. For ten averages of a signal, 42 seconds of elapsed time is needed, or about 4.2 seconds per acquistion. Of this, about 1 second is needed to write information to the DPO screen per acquisition. For 21 averages, about 65 seconds of acquisition time is required, or about 3.1 seconds per acquisition. This is about a 35% reduction in acquisition time overall per signal. The improved time per acquisition is due to the reduced frequency with which data in the form of the wavecount is written to the DPO screen. For a relatively small increased investment of time, a tremendous advantage is realized in averaging signals and reducing polluting noise. A further decrease in acquisition time per signal is realized when 101 or more averages are specified. However, as will be discussed in Chapter V, lack of total signal stability may produce errorneous results for such a large number of acquisitions due to the length of time required.

In lines 2570-2820, the waveform scale factors are determined and transferred to the processor. The values are returned in M$ (vertical magnitude scale factor) and T$ (horizontal time scale factor). The discrete, digitized verticle values are appropriately scaled to the correct real time values in line 2700. The time between a single discrete sample on the horizontal axis (sampling rate) is returned in Z1 at line 2820.

In summary, ACAVG does the physical acquisition, averaging and scaling of each signal. It returns the current waveform count to the DPO CRT for display, and the appropriately scaled waveform in XO to the driving subroutine for storage in the appropriate file. It further returns the appropriate horizontal and vertical axis labling scale factors in T and M respectively. The flow diagram for ACAVG is provided in Figure 4.5

The basis for this subroutine was derived by Capt. Hammond. [Ref. 19] His program in its entirety has been extensively modified to fit the current requirements of the TDRL OS.

e. Subroutine NEWPAR/ANTIN/TGTIN

NEWPAR, ANTIN and TGTIN are interactive subroutines which allow an operator to input new parameters for defined antennas and targets into the mass storage library on Data Storage Tape 2.

NEWPAR is the driving routine for ANTIN and TGTIN. It receives its input from the DRIVER and selects either ANTIN or TGTIN. It returns the new parameters to the appropriate file on the storage tape. NEWPAR then determines if further inputs are required. If not, program control is returned to DRIVER.

ANTIN defines the values of the parameters of the new antenna. It requests the operator to input the

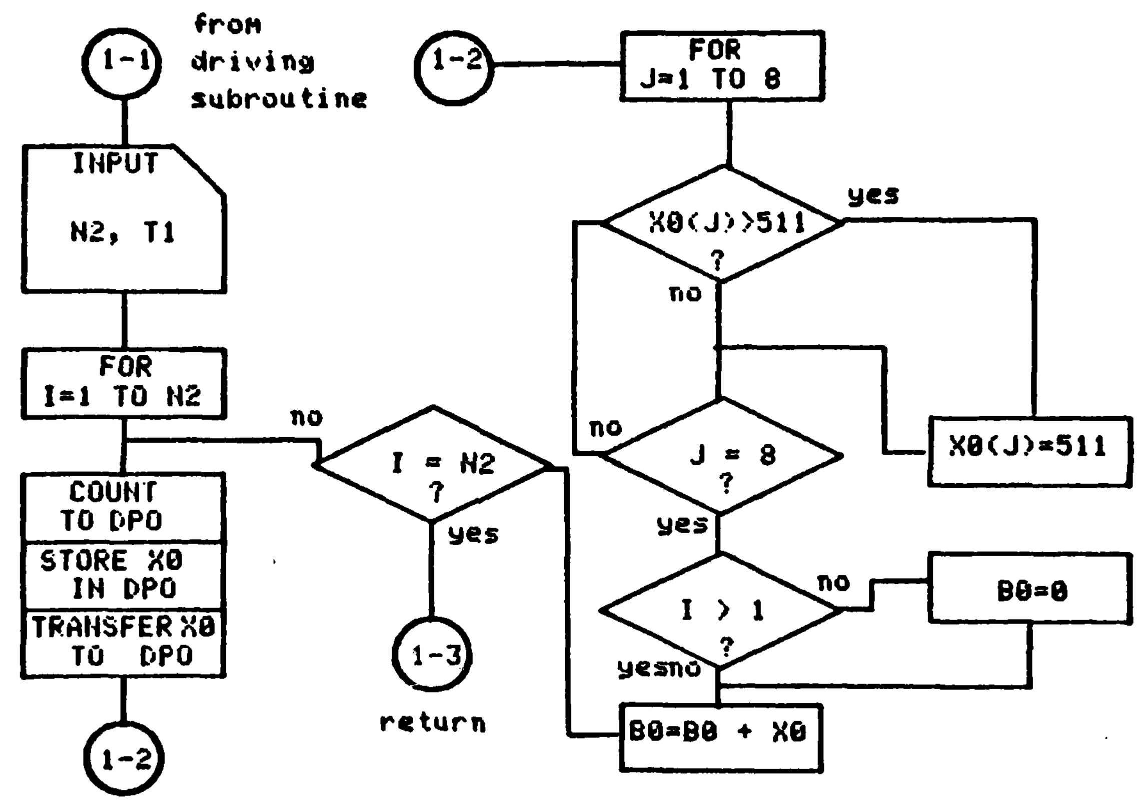


Figure 4.5. Flow Diagram--INPUT ACAVG

antenna number. An array of 63 elements is then generated, each third element being filled with an initial antenna run number equal to 1. All other elements are set to zero. If the operator specifies an antenna value greater than 20, the following message is returned.

"STORAGE AREA LIMITED TO 20 ANTENNAS. WANT TO CONTINUE?"

This is necessary as current space limitations limit the number of antennas to be defined.

TGTIN defines the values of the parameters of new targets. It requests the operator to input the new target number as well as the length and radius of the target. The carraige return must be pressed after each entry.

NEWPAR, ANTIN and TGTIN are located in lines 4200-4800. They comprise 11% of the program.

f. Subroutine SCATWAV

SCATWAV determines the target backscattered waveform based on the differance of the augmented and incident waveforms. It returns the backscattered waveform to storage at file 53 on Tape 2. It also sets flag P7 to the appropriate value required for either Prony processing (P7=1) of Time Domain processing (p7=0). Program control is then returned to INPUT DRIVER.

2. Program MATH

MATH performs most of the significant mathmatical computations for the OS. Its correct performance is central in the production of accurately processed signals. MATH is stored on Tape 1, File 3. It requires 14544-bytes of CPU memory space. With all arrays and constants defined, a maximum total of 49108-bytes of memory are required.

This sub-program is initiated under program control only from INPUT and GRAPH. There is no interaction between operator and system during MATH's execution.

Inputs to MATH are from INPUT, GRAPH or Tape 2. Values are returned to mass strorage or GRAPH.

MATH performs the following functions for the OS:

1. Fast Fourier transforms the Direct and Backscattered waveforms.
2. Determines the frequency domain impulse response.
3. Performs inverse Fourier transform to find the time domain inpulse response.
4. Determines the step and ramp response for the target.
5. Determines the physical optics shape of the target.
6. Optimally filters the frequency domain impulse response, yielding a smoothed time domain impulse response, ramp response and physical optics shape of the target under noisy conditions.

7. Compensates the ramp response and optics shape for EM propagation attenuation.

8. Updates optimal antenna parameters for the antenna being used, based on the targets ramp response, automatically.

MATH is composed of four subroutines and DRIVER. A description of each follows. A general flow diagram for MATH is given in Figure 4.6.

a. MATH DRIVER

The driver routine for MATH is located between lines 100 to 1210 and comprises 59% of the total program. In addition to initializing the program and driving the subroutines, DRIVER performs most of the significant mathematical computations in straight line data flow fashion.

MATH DRIVER is initiated at line 100 from INPUT or line 130 from GRAPH. Parametric data is input directly from INPUT. It is recovered from mass storage in line 160 if GRAPH initiates MATH. Lines 100-221 serve to initialize the local program parameters.

Line 250 inputs into X0 from mass storage file 53 the signal (backscattered waveform) which represents the convolved transient response of the transmitting antenna,

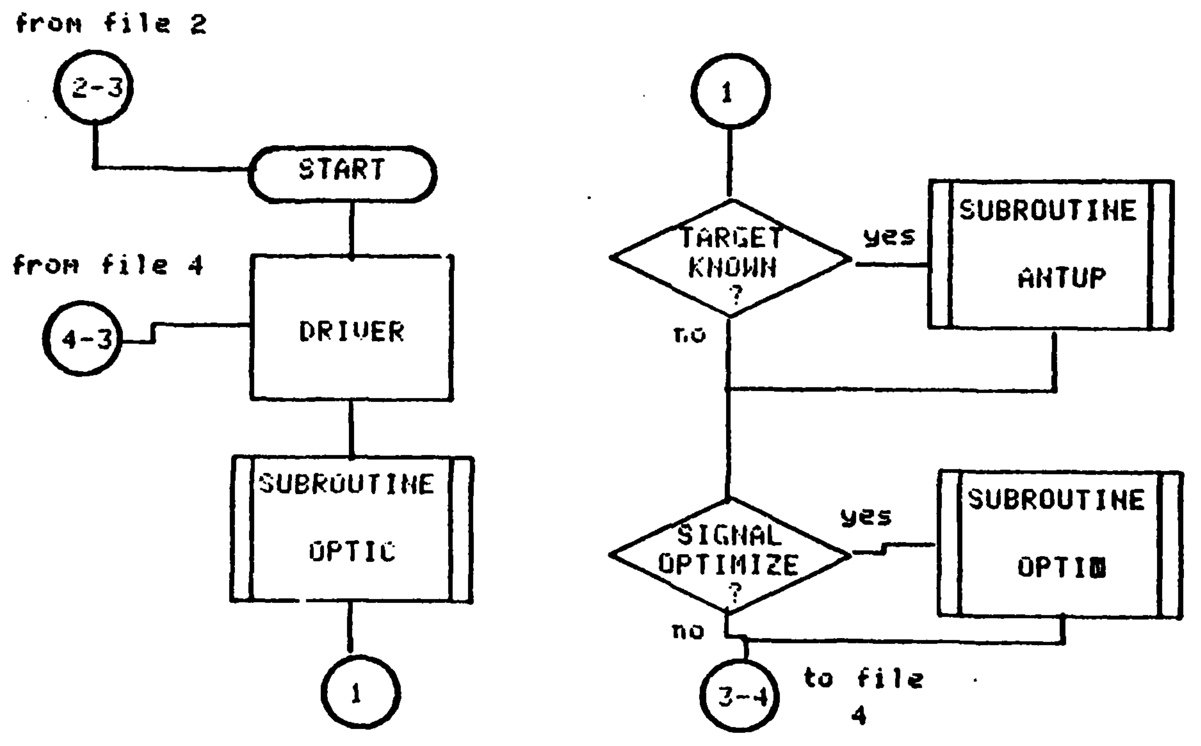


Figure 4.6. General Flow Diagram--MATH

the receiving antenna, and the target. This data is then used to drive subroutine FFT. X0 is returned from FFT in M and P as the frequency domain magnitude and phase and saved in arrays E and E3 respectively.

A similar procedure is performed in lines 290-340 for the convolved transient response of the transmitting and receiving antennas without target on the ground plane. The magnitude and phase are returned in arrays F and F3 respectively.

In lines 360-420, the frequency domain impulse response of the target and noise optimization are performed. Magnitude of the impulse response is returned in E0, with phase returned in F0. The algorithm for determining the impulse response and performing optimization were developed in chapter III and will not be repeated here.

Lines 440-540 perform the inverse Fourier transform of the frequency domain impulse response of the target to find its time domain equivalent. The frequency domain data entering at line 440 is in polar form. This form is most suitable for the previously described mathematical manipulations. It is not a suitable form for the inverse Fourier transform method employed by the 4052 system. In order to perform this operation, the magnitude and phase arrays must first be converted into two source arrays containing real and imaginary data. Next, the first element of the real array must contain the signal dc term, while the last real element must be the Nyquist frequency value. As both these elements represent pure real numbers, the first and last elements of the imaginary source array muse be correspondingly zero.

Lines 440-470 establish a FOR/NEXT loop that returns real terms to M and imaginary terms to P. Real terms are established by multiplying the polar magnitude, E0, by the cosine of the corresponding phase F0:

$$M(j) = E0(j) \times (\cos (F0(j)) \qquad (4.3)$$

Imaginary terms are established by multiplying the polar magnitude by the sine of the corresponding phase term:

$$P(j) = E0(j) \times \sin(F0(j)) \qquad (4.4)$$

INPUT had previously removed all dc levels prior to MATH, so M(1) and M(257), the dc and Nyquist terms, are set equal to zero in lines 480-490. Lines 500-510 set the corresponding imaginary terms to zero. Note that both of these arrays must be 257 data points long, as the output array will be 512 data points.

Data is now correctly formatted in the two source arrays so that the command "INLEAV" can interleave the real and imaginary data into a single destination array, IO, whose format is acceptable to the GS "IFT" command.

Line 540 calls the system inverse Fourier transform command "IFT" which transforms the spectral data into waveform (time-domain) data. The spectral data originally in IO is overwritten by the new time domain data and returned in IO. IO is now the time domain impulse response.

The inverse Fourier transform can be expressed mathematically by the following summation:

$$X(n) = (1/N) \sum_{k=0}^{N-1} X_d(k)\, e^{j2\pi nk/N} \quad , \text{ for } n=0,1,\ldots,N-1 \qquad (4.5)$$

In the above equation, N refers to length of the array argument, and n is an index used in generating the various elements of the output array. X (k) is the k-th complex Fourier coefficient, and X (n) is the n + 1-th element of the real data output. [Ref. 20] The 4052 uses an extremely fast method for IFT computations, the Sande-Tukey decimalization-in-frequency algorithm.

Line 620-720 save the time domain impulse response (file 54), and frequency domain direct waveform (file 55), the backscattered waveform (file 56) and the impulse response (file 57) in mass storage.

Next, the time domain step response of the impulse is returned to X0 in line 740 by using the 4052 "INT" routine. This is an integration calculated using the trapezoidal rule for approximating the definite integral as follows:

$$B' = 0$$

$$B(t) = B(t-1) + .5 * (A(t-1) + A(t)) \qquad (46)$$

for $t = 2,3,\ldots,N$

where: A = the source array

B = the destination array (result)

N = the number of elements in the array

Any dc value in the result is removed through the actions of lines 750-760.

Next, the time domain ramp response is determined by integrating the step response in X0. The ramp is returned in R0. The MATH DRIVER outputs the time domain ramp and its minimum value in R2 to Subroutine OPTICS which returns the physical optics shape (shape) and ramp response compensated for electromagnetic propagation attenuation.

Note the shape does not as yet have the correct amplitude values in its array elements.

If the run is the first for the target (prior to optimization) and the target is one defined in mass storage, MATH DRIVER inputs the last computed antenna parameters for the compensator for shape length (S5) and radius (S6), as well as the actual defined lenghth (C6) and radius (C5) to subroutine ANTUP. S5 and S6 are then automatically updated. The physical optics array is then multiplied by the compensator value S6 so that its elements reflect the estimated dimensions of the targets in inches. This is based on the experimentally observed fact that a particular size and configuration of stationary target will return some backscattered field relative to its size and shape. That this value is not exactly the same from one run to the next, but only approximately so, is due to certain stastically determinable effects produced by noise, small differences in orientation, etc. A large number of runs should produce an averaging value which takes into account these factors. If the target is unknown (the general case), or the current run is for noise reduction, previously computed values of the antenna parameters are recalled from mass storage. For the unknown target these compensators are the averages for all targets for all runs for a particular antenna. In fact, OPTICS is not part of the data processing flow, the compensators having been previously determined in INPUT at lines 1024-1025.

Following a known target run, the minimum value of B0 is returned to B8. If the run is not for optimization (L1=1), then B6, an amplitude compensation optimization factor is set equal to B8 and the actual length of the shape is retained in Q9. For graphing purposes, it is desirable that B6 and Q9 not vary from optimization run to optimization run. MATH DRIVER will input B0, Q9, and B6 to subroutine OPTIM, which compensates the amplitude and length of the physical optics shape for the low pass filtering done to reduce noise. An arbitrary target is treated in exactly the same manner. (Note, this effects the shape ONLY and not the time domain ramp response during optimization.)

The above system has worked remarkably well in deducing the actual physical parameters of both known and unknown targets. For known targets, accuracy is invariably 10% or less. For unknown targets, this accuracy deteriorates to about 15% or less. If the data is treated in the raw form, with no compensation applied, accuracy is reduced to 25% or worse, up to 50% for the unknown target.

This can be noted on the graphic output of the shape where the compensated, uncompensated and known (when given) values of length are compared run to run.

Lines 1000-1140 save the updated antenna parameters in the appropriate files, the shape array in file 58, the time domain ramp response in file 59, and significant system parameters in file 60, all on mass data storage Tape 2.

Lines 1160-1190 is MATH DRIVER ending routine, deleting variables and passing control of the program to GRAPH (file 4) on Tape 1.

In summary, MATH DRIVER is the principal vehicle for OS processing for inverse scattering. A flow diagram is given in Figure 4.7.

b. Subroutine FFT

FFT is the fast Fourier transform subroutine used to convert the time domain Direct and Backscattered waveforms to spectral data. This subroutine is located in lines 2000-2140 and requires 7% of the total program space.

X0 contains the real-valued signal data on which the Fourier transform is to be performed. It is input from MATH DRIVER. Line 2060 calls the GS command "FFT" and performs a fast calculation (about 4 seconds) of the DFT

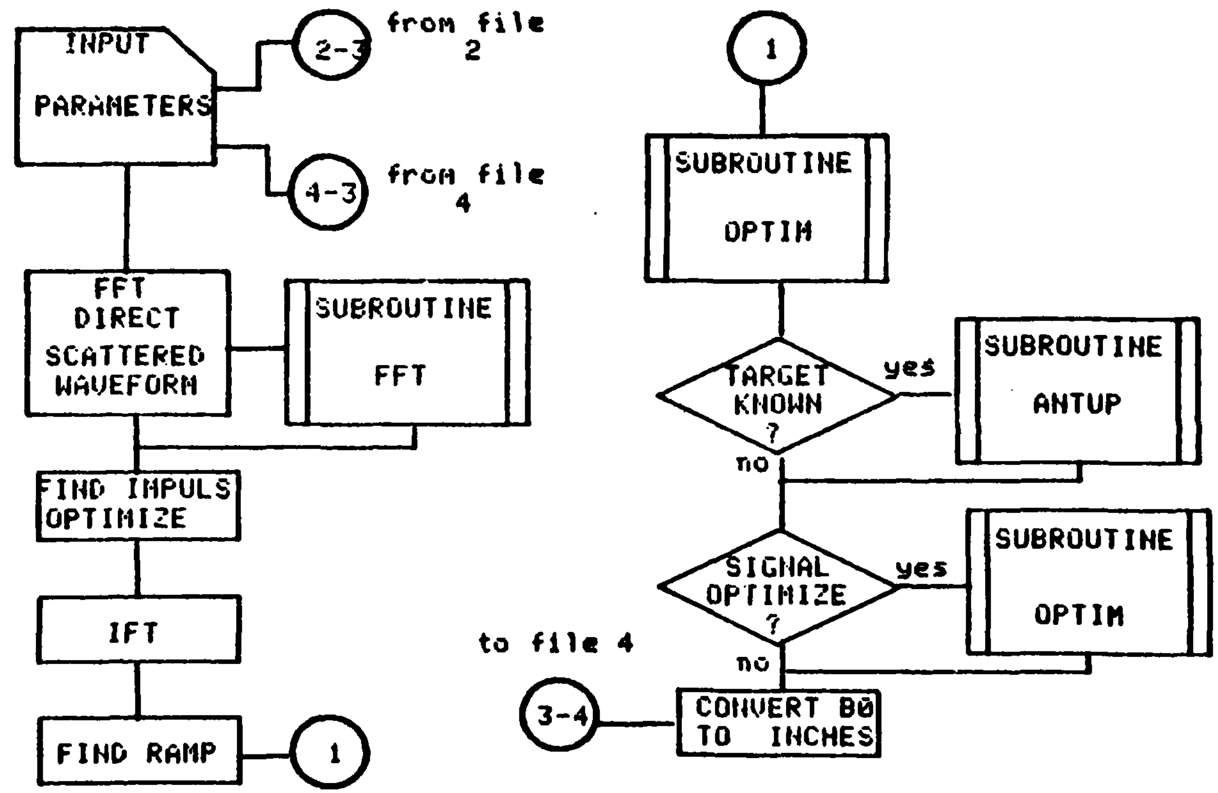


Figure 4.7. Flow Diagram--MATH DRIVER

(discrete Fourier Transform), expressed mathematically by the summation: [Ref. 21]

$$X_d(k) = \sum_{n=0}^{N-1} X(n)e^{j2\pi nk/N} \quad , \text{ for } k=0,1,\ldots,N/2 \qquad (4.7)$$

where: N = array length

k = index used in generating various Fourier coefficients

$X_d(k)$ = k-th Fourier coefficient

$X(n)$ = n + 1-th element of the real data input

After the command has executed, the original real data will be overwritten by the results of the FFT computation. The output data is in complex rectangular form with the first element of the array X0 containing a real number representing the dc value of the signal, the second element containing a real number representing the value of the discrete Fourier transform at the Nyquist frequency, and the remaining array elements containing alternately real and imaginary Fourier coefficients.

This arrangement is not suitable for the division that later takes place. In line 2070, the rectangular array X0 is converted to polar form by calling the GS command "POLAR". Magnitude components are returned in array M and phase components are returned in array P. At this point, subroutine FFT returns control to MATH DRIVER with the arrays X0, M and P for further processing.

c. Subroutine OPTIC

Subroutine OPTIC manipulates the ramp response of the target to recover the physical optics shape, but it does so without effecting in anyway the raw data. It later compensates both the ramp response and the shape for EM propagation attenuation experienced along the body of the target. Subroutine OPTIC resides in lines 2200-2700 and comprises 25% of Program MATH.

The ramp response R0 and the location of its minimum value within the array are input into OPTIC from MATH DRIVER. The mean value of the response is calculated in lines 2250-2260 and returned in R3. This value is used later in determining the endpoints of the shape array.

Lines 2290-2500 is a FOR/NEXT loop that seperates out the targets shape from the ramp array data. The search for valid data begins at the point in the array equal to the location of the minimum value. It is assumed that the target will always return a response larger than any that might be due to range noise or other excitation. For the size of the targets being used, and the the configuration of the present source, this has always proven to be an accurate assumption. The FOR/NEXT loop searchs first for a trailing-edge endpoint. This is done in ascending time steps in search of the point where the array elements become zero or positive, representing a zero-axis crossing. For every value of R0 less than zero, a corresponding value is input in B0, the shape array. If B0(k) is a positive value, representing a zero-crossing, the FOR/NEXT loop is terminated. If B0(k) is negative, OPTIC then checks the location of the point. It is important to do this as noise and instability of input signals from an acquisition-to-acquisition run may erroneously shift-zero crossings or preclude zero-crossings altogether. In these cases, determination of the shape must be somewhat modified as described below.

In line 2350, two situations are checked. First, is the preceding array element of R0 more negative than the present element and is the present element greater that 90% of the ramp response average value. If affirmative, the next array element is fetched. A positive result of this check indicates that datum is on the skirt of the ramp response, and that the data magnitudes are progressing towards a zero-axis crossing normally. If the check returns as negative, that is, the present array value is more negative than the preceding element, than an anomaly has occurred either due to noise, or time-axis shifting. In this case a special endpoint routine must be employed.

The second check is to determine if the array element is on the main signal portion of the response and not the skirts. If the element amplitude is greater that 90% of the mean value, than it is assumed that the element is on on the skirt irregardless of the relationship between the amplitude of the present and preceding elements. The next datum is fetched. It can be seen that this arrangement is subject to some error if a noisy element is encountered just at the point where the ramp response passes the 90-th percentile of the signals mean value. This error is considered relatively minor.

The 90-th percentile was chosen following numerous observations that noise or time-shift in the main ramp response normally do not produce fluctuations that cross this boundary. Error in the shape representation will be introduced if it does, in fact, cross this level. The result will be a fore-shortened drawing of the target.

If the need for an endpoint routine is indicated, processing goes to lines 2360-2470. In line

2360-2380, the distance the last valid data element (R0(k-1)) is from the zero axis is determined. In line 2360, the distance between the previous two valid data elements is found and returned in W(3):

$$W(3) = R0(k-2) - R0(k-1) \qquad (4.8)$$

The above is for the ascending time series run of the FOR/NEXT loop (trailing edge). For the descending time series, the values in the parenthesis have opposite sign. This difference represents an approximation of the slope of the skirt. A problem with this approximation is that it often occurs where the slope is not as great as the average. The result is a somewhat elongated figure. It may be possible to defeat this problem by taking more than two points for the average.

In lines 2370-2380, a check is made to see if the last valid data point is within 10-times or less of the difference determined above. If it is, the actual difference is returned in Q1 and used to drive the values placed in B0 to a zero-crossing. If the difference is less that 10% of the amplitude needed to effect a zero-crossing, then one-tenth of the actual distance is returned in Q1. In this manner, the shape rapidly goes to zero and an endpoint is determined close to the estimated real endpoint had a natural zero-crossing occured. The endpoint is located with a FOR/NEXT loop between lines 2420-2470. This FOR/NEXT loop simply iterates the values of B0 by Q1 until a zero-crossing is effected. Whenever B0 becomes positive, all loop processing is terminated and the endpoint is returned in W(1) for the trailing skirt and W(2) for the leading skirt.

If the above process was for the leading edge of the ramp response, the loop is reentered and the trailing edge check of the data is performed. The method employed is identical with the above process for the leading edge. Note that up to this point, the ramp response in R0 has been totally unaffected by any processing in OPTICS. It has been used simply as source of data.

Once the target response has been located in R0 and entered in B0, then both arrays can be compensated for propagation losses experienced. This is done in lines 2570-2640. The value of the nominal distance the target is from the transmitting antenna is returned in Z6. A FOR/NEXT loop in lines 2590-2640 corrects the arrays for the estimated propagation losses. Line 2600 computes the distance along the body the wave propagates for each sample point in R0:

$$R = (Q - W(1) * Z1 * (10*8)/2 \tag{4.9}$$

where: $(Q - W(1)) * Z1$ = twice the time of travel of the propagated wave

In line 2610, the propagation loss compensation factor is returned using:

$$U = \frac{(Z+R)(2Z+R)}{2Z^2} \tag{4.10}$$

where: Z = range from transmitting antenna to target face

It is also assumed that the distance between transmitting and receiving antenna is Z. Z is in fact the measured value of distance read from the "TIME/DISTANCE" dial on the DPO. Each value of R0 and B0 is then multiplied by this compensation factor in turn. Processing continues once all values for the computed length have been appropriately amended.

Line 2260 is a FOR/NEXT loop that transfers the values in the array B0 to the beginning of the array to facilitate graphing. Once this is accomplished, program control is returned to MATH DRIVER with the shape unscaled for actual dimensions of the target (values are equal in amplitude to the compensated voltage magnitudes of the ramp response). The ramp resonse is returned uneffected by any of the above processing except for propagation attenuation compensations. Figure 4.8 provides a flow diagram for Subroutine OPTICS.

d. Subroutine ANTUP

This surboutine updates the specific antenna length and radius compensation values if the target is one defined from storage on Tape 2. If the target is arbitrary in the general case, no updating occurs. ANTUP is located between statements 3000-3080 and comprises 4% of the program.

The unscaled shape array B0 is input to ANTUP from MATH DRIVER. In line 3060, the amplitude compensating and scaling factor is computed using:

$$S6 = (A + S*B)/(C*B)$$

where: S6 = scaling/compensating amplitude factor

C = radius of target

B = minimum magnitude of physical optics array

A = the number of previous times this antenna/target combination was used

S = sum of previous compensation values

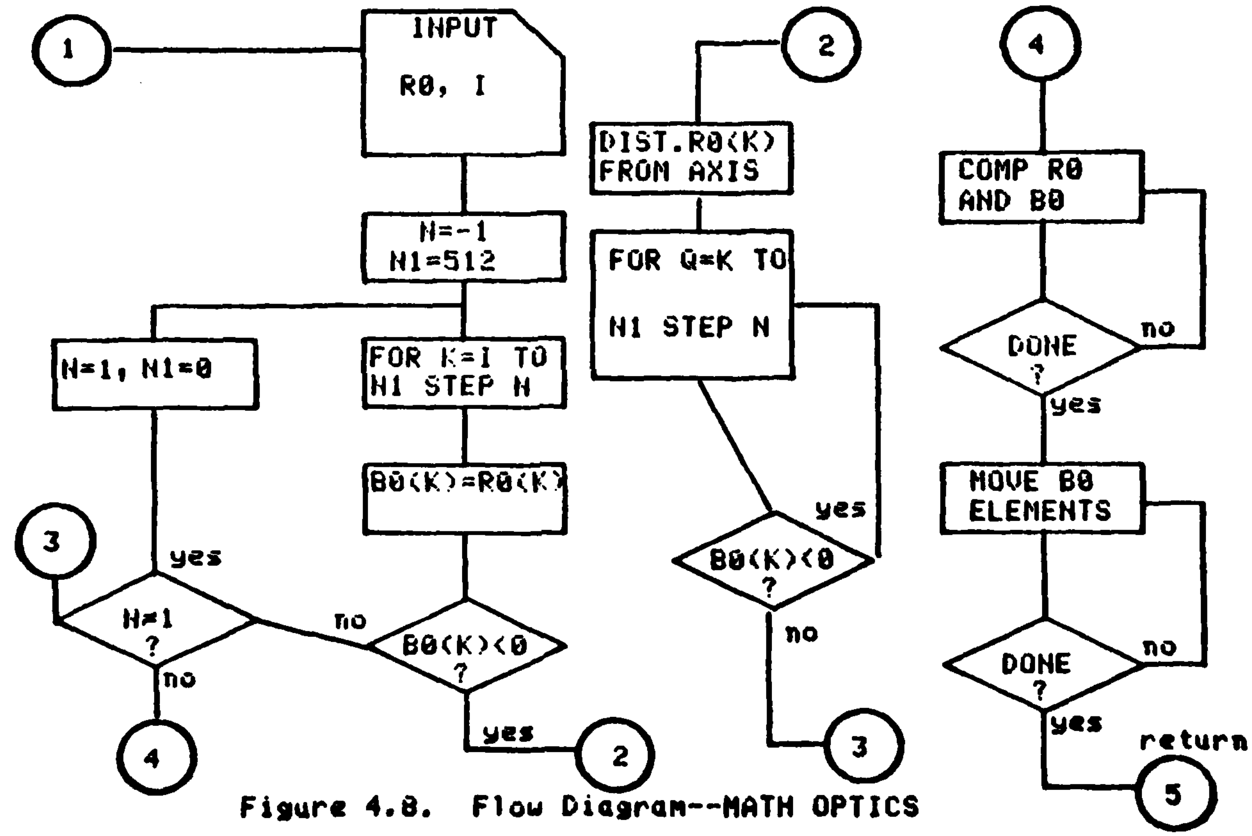


Figure 4.8. Flow Diagram--MATH OPTICS

The result is simply the averaged value of compensation/scaling for all runs using this particular antenna and target combination.

Line 3070 performs a similar computation for S5, updating the compensation/scaling factor for the target length. The formula is identical except that the defined target length replaces the target radius and the observed or measured length from the plane replaces the minimum magnitude of the shape array. The concept is that slight differences in target returns due to variations in target location and orientation, noise, etc., will be averaged out over the long term for any particular antenna. When the target is arbitrary and there is no a priori information then ANTUP is bypassed and the average of all the compensation/scaling factors for all targets for the particular antenna is used. This requires that any new antenna be "seeded" with compensation/scaling factors from at least one run using known targets prior to attempting to run an arbitrary target on the antenna. What results is a "poor man's" compensator for the currents on the body of the target based on empiracal observations of many target responses. It is not as accurate as the full solution of the time domain integral equations would be, nor is the exact target shape returned. What is obtained is an excellent estimate of the target, whether known of unknown, based on an historical compilation of data for the TDRL system. This concept can be generalized to any system using components which are nominally fixed, such as large scale bistatic radars. The shape itself, at least for simple axisymmetric targets, can probably be returned with the development of the proper software routines. Perhaps the rate at which the ramp response slopes vary may be analyzed for this purpose. What is obtained is a method which employes a small scale processor requiring relatively simple processing to obtain accurate time domain estimates based on the ramp response of the target almost in real time, and capable of being generalized to almost any system employing the proper source.

The compensation/scaling factors are returned to MATH DRIVER along with program control. B0 is unaffected as yet by S5 or S6.

e. Subroutine OPTIM

OPTIM compensates the shape array for the effects of low-pass filtering of the target responses using Riad's Optimization technique. Optimization is done to remove high-frequency noise terms and, for the shape, to improve the overall shape of the drawing. In reality, without compensation, the drawing is less representative of the true targets shape when optimized. Low pass filtering will lengthen the overall shape and reduce the radius, the amount being relative to the value of lambda, the optimization variable. OPTIM allows for this and introduces factors which will pin the optimized shape to the original form while allowing the benefits (reduced noise ripple on the body) of low-pass filter noise reduction to be shown. OPTIM is located in lines 3100-3180 and represents 4% of the program.

B0, B6, (original minimum of the unoptimized shape), B8 (the present minimum of the shape) and Q9 (the original unoptimized target length) are input from MATH DRIVER. The amplitude OPTIM compensation is found in line 3140 by dividing B6 by B8. It is returned in B7. The new compensated target length factor is returned in Q7 and is found by dividing the present value of the length by the original value. Finally the whole physical optics shape array is scaled by the new amplitude factor. The new values are returned to MATH DRIVER, along with the original factors in B6 and Q9. In fact, after the initial unoptimized run, B6 and Q9 are constants until a new target is acquired.

3. Program GRAPH

GRAPH provides a central means to visually display the results of processing performed in MATH . The correct evaluation and analysis of the acquired processed data is a direct function of the effective reproduction of the resultant arrays by GRAPH into a form most useful and understandable to the operator. GRAPH is located on Tape 1, File 4, and requires 44712-bytes of memory space.

Program GRAPH is normally initiated under program control from Program MATH, in line 100. It may be initiated directly by the operator if the results of a previous run have been retained in mass storage. The commands issued by the operator are:

FIND 4

CALL BOLD

RUN

Outputs are to the CRT or a return of control to one of the other programs that make-up the TDRL OS. No results are returned to mass storage.

GRAPH subroutines may be divided into three categories:

1. DRIVER--provides for initialization of the program and drives subroutines. It also passes control to the next program in the OS.

2. AXIS and Labling Subroutines--establishes the axis of all graphs and lables as appropriate. Provides for formatting of descriptive parameters, as appropriate builds grids for graphics. Six subroutines comprise this group. They are AXIS, TICKS, AXLAB, TITLE, GRPAR, GRID.

3. Inverse Scattering--Subroutines in this section graph the results of processing in INPUT and MATH. They reproduce the four basic input waveforms, the Fourier transforms of the Direct, Backscatter and Impulse Response, the Physical Optics Shape of the target, and the time domain ramp response. Four subroutines comprise this group. They are GRIN, GRFOUR, GROP, and GRAMP.

A general flow diagram for GRAPH is provided in Figure 4.9. A disscussion of all Subroutines in GRAPH follows.

a. Graph DRIVER

As for INPUT and MATH DRIVER, GRAPH DRIVER is the principal initializer and controling routine for this program, coordinating the flow of processing. Unlike MATH DRIVER, GRAPH DRIVER does not of itself perform any data processing. That function is retained for the subroutines exclusively.

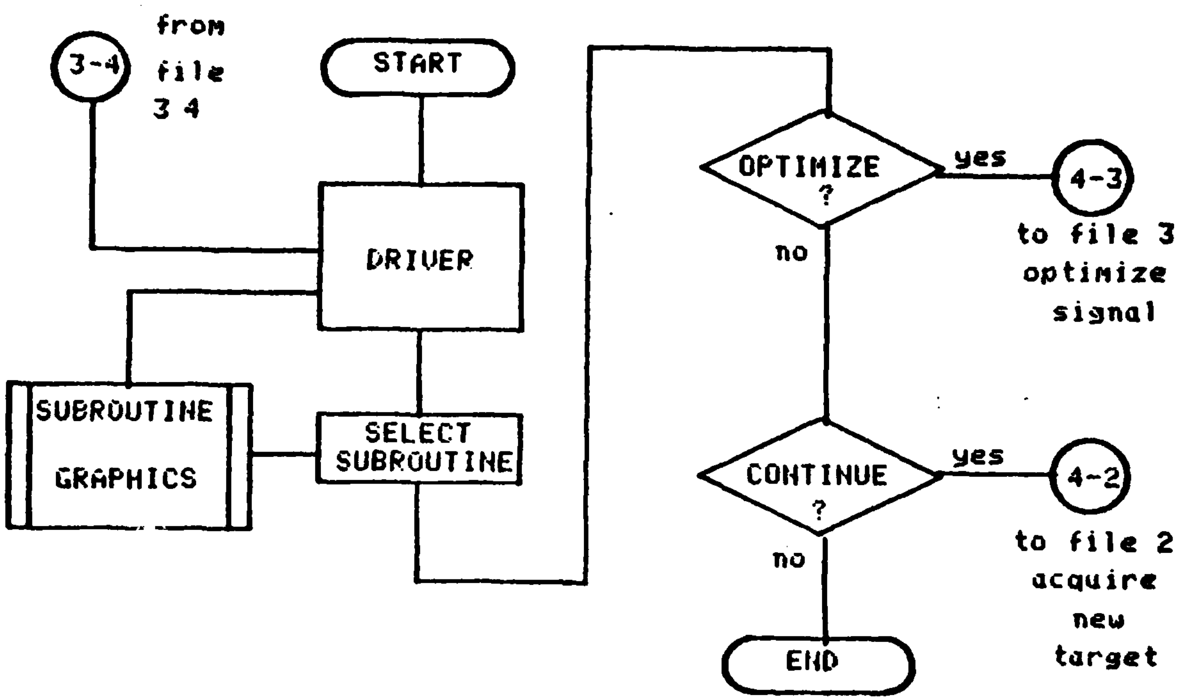


Figure 4.9. General Flow Diagram--GRAPH

GRAPH DRIVER is located in lines 100-1190 and comprises 19% of the total program. GRAPH is completely independant of data input from the other programs in the OS. All inputs are from mass storage Tape 2 or the GS keyboard. All results are returned to CRT display of the 4052. This routine is highly operator-processor interactive. Appendix F describes a typical run with messages as produced.

GRAPH DRIVER is always initiated in line 100 when being entered external to the GRAPH Program. It is initiated from line 290 by returns from internal subroutines. Lines 100-300 initialize the program and input parameter data from mass storage. Lines 320-750 develope the correct Menu, with the function/subroutine selected input to P0 in line 760.

The Menu that is used in GRAPH Iis shown in Apendix F. Most of the fiunctions on the menu are self-explanatory. A few remarks concerning items 10, 11, 12, and 13 should suffice to remove any ambiguity.

Item 10, "CONTINUE OPTIMIZATION", initiates the Riad low-pass filtering optimization of the impulse response in lines 950-1030. Program control with the operator designated optimization factor is input to Program MATH.

Item 11, "NEXT TARGET", passes program control to INPUT for the acquisition of an entirely new target. Parameters are retained and passed along with program control.

Item 12, "FINISHED GRAPHING", terminates processing. The program can be reinitialized by typing "RUN".

Lines 820-900 select the appropriate subroutine and functions. Line 940 returns to the menu for further selection for all items except 10,11, 12, 13.

The next series of subroutines to be discussed perform the graphics axis formatting, labling and titling. These subroutines set the environment that makes the information of use to an observer. AXIS,TICKS, AXLAB, and TITLE are subroutines based on programs previously developed by Tektronix, Inc. [Ref. 22] All have been modified to a greater or lesser degree dependant on the needs of the TDRL.

b. Subroutines AXIS/TICKS/AXLAB

Subroutine AXIS drives Subroutines TICKS and AXLAB. They perform the general axis definition function for the output graphics. Subroutine AXIS serves as the input portal for data from the function subroutine that was chosen by the operator. The results returned to the CRT of the GS are "neat" ticks, labled and scaled to the proper values of the input function. Subroutine AXIS occupies statements 2000-2250, TICKS is in lines 2300-2610 and AXLAB is in statements 2700-3190. These three subroutines occupy 18% of program space.

Data input from the function to be graphed are the minimum and maximum horizontal values of the viewport in V1 and V2, and the minimum and maximum vertical values of the viewport in V3 and V4. These constants are in Graphic Display Units (GDU). GDU's are a measure of the resolution capability of the GS screen. The four arguments defined above refer to the actual limits for the graphic information of the display. The GS will draw no lines outside these limits.

Also input to Subroutine AXIS from the driving function subroutine are the minimum and maximum horizontal values of the function itself, W1 and W2, and the minimum and maximum vertical values, W3 and W4. These values are in User Data Units (UDU's). That is, in units that the user defines, such as millivolts, seconds, meters, etc.

Finally, AXIS receives the value of the flag S0. This specifies whether the vertical axis (S0=0) or horizontal axis (S0=1) is being labled. The magnitude of the horizontal scaling function for the input wave, S1 (received from INPUT), and the definitions in UDU's for the vertical axis and horizontal axis are required.

The performance of AXIS, TICKS, and AXLAB is adequately described in the Tektronix source referances. [Ref. 23] This report will describe only those statements which have been changed or modified to produce the desired output for TDRL purposes.

Principally, the changes effect the manner in which the axis is lable with UDU's in Subroutine AXLAB. These changes lie in statements 2860-3190. Three conditions must be checked:

1. Horizontal (S0=0) or vertical axis (S0=1) lables?
2. Graphics of a Fourier transform? (4<P0<8)
3. Check amplitude of maximum vertical value (P6) in UDU's.

TABLE IV defines the relationship between statements in Subroutine AXLAB and the functions to be graphed.

c. Subroutine TITLE

This subroutine positions the title of the graphic above the plotted values. It is located in lines 3200-3310 and comprises 2% of the program. The value of the maximum horizontal coordinate W2 and the graphic computed

TABLE IV

Graphic Labling Relationships--GRAPH AXLAB

GRAPH	STATEMENTS	REMARKS
GRIN GRAMP	HORIZONTAL AXIS	HORIZONTAL AXIS
	2880-2890	S1*10≥1000. Lable Axis
	2910	S1*10<1000. Lable Axis
	3090	Position Dimension Lable
	3110	Dimension Lable
	3140-3160	Print Dimension Lable
	3180-3190	Return
	VERTICAL AXIS	VERTICAL AXIS
	2860	Start
	2940-2970	P(6)<1. Lable axis
	2980-2990	1≤P(6)<10. Lable axis
	3000-3010	P(6)≥10. Lable axis
	3130-3150	Print Dimension Lable
	3180-3190	Return
GRFOUR	HORIZONTAL AXIS	HORIZONTAL AXIS
	2861-2862	
	2863-2864	"Magnitude" Axis Label
	2865-2866	"Phase" Axis Lable
	3171	Print Dimension Lable
	3180-3190	Return
	VERTICLE AXIS	VERTICLE AXIS
	2860-3170	Same as for Horizontal Axis
	3173-3190	Return

NOTE: All graphic routines use lines 3020-3040 vertical maximum P(6) are input by the graphic subroutine. The graph title centered over the graph is returned to the CRT.

d. Subroutine GRPAR

GRPAR graphs the parameter input by INPUT and developed by MATH. This subroutine is located in lines 3400-3870 and comprises 8% of the program. All graphs have the run number, date, target distance from transmitter, antenna number, target number, averages taken, optimization and any specific remarks printed. The specialized parameters printed for particular graphs alone with the statement number applicable are given in TABLE V.

TABLE V

Specialized Parameter Prints--GRAPH GRPAR

GRAPHIC	PARAMETERS	LINES
GRIN GRAMP	MAXIMUM PEAK VALUE	3510-3600
	MINIMUM PEAK VALUE	
	RMS VALUE	
	MEAN VALUE	
GROP	DIAMETER (INCHES)	3710-3750
	WIDTH (INCHES)	

e. Subroutine GRID

This simple subroutine draws referencing grid lines on the appropriate graphic. The computed graph maximum and minimum are input from the graphic subroutine along with the axis tick intervals. Grid lines are output to the CRT from GRID. Lines 3900-4010 contain the subroutine. GRID requires 2% of program space.

This concludes the discussion of general graphics formating subroutines. The driving graphic subroutines will now be discussed.

Subroutines GRIN, GRFOUR, and GRAMP are all similar in formatting structure. With some judicious choice of programming flags and routine definition, it should not be too difficult to combine these three subroutines into a single driving graphic subroutine. GROP is formatted differently, but still retains a few features common to all the graphic driving subroutines. The similarities between the subroutines will be discussed first. The particular differences applicable will be discussed secondly.

Each graphic subroutine is composed of four basic blocks. They are:

1. Input waveform data from mass btorage
2. Define waveform and graphic boundaries

3. Draw the graph of the function using special defining functions when necessary

4. Labling the graph with the correct title(s)

GRAPH DRIVER inputs the function value PO which is used to identify the location of the data storage file in which the appropriate data rests. This single row array is usually returned in X. The waveform window and viewport parameters, bounding the output graphic display, are next determined. The maximum horizontal axis values are found by mutiplying the distance between a single data point (in UDU's) by the total number of data points in the array along the X-axis. For those waveforms listing the mean graph values as part of the descriptive parameters, the sum of all the array element values is obtained and then divided by the discrete number of array points:

$$\text{Mean} = WS = \sum_{i=1}^{N} x(i)/N \tag{4.11}$$

To ensure that the function is graphed along the zero axis of the formatted graphic, the means are subtracted from the array elements. In similar fashion, the root mean square is found:

$$RMS = W6 = [\sum_{i=1}^{N} x(i)^2/512]^{1/2} \qquad (4.12)$$

The maximum and minimum values for the input data are found by implementing the 4052 call "MAX" and "MIN" routines. These values are returned in W4 and W3 respectively. The values are then output to the axis defining subroutines for establishment of appropriately scaled and labled axis.

Next, the GS cursor is positioned to the beginning of the array with a "MOVE" command. For the number of discrete data in the array, the function is graphed on the GS CRT. Finally, the graphic is titled and identified by the appropriate parameters. Figure 4.10 provides a general flow diagram of the graphic driver routines.

The particular aspects of each graph will now be briefly discussed.

f. Subroutine GRIN

This subroutine is the driving graphic for the display of the inputted Direct, Incident and Augmented Waveforms, and derived Backscatter waveform. It resides in statements 5000-5410 and makes-up 7% of the program.

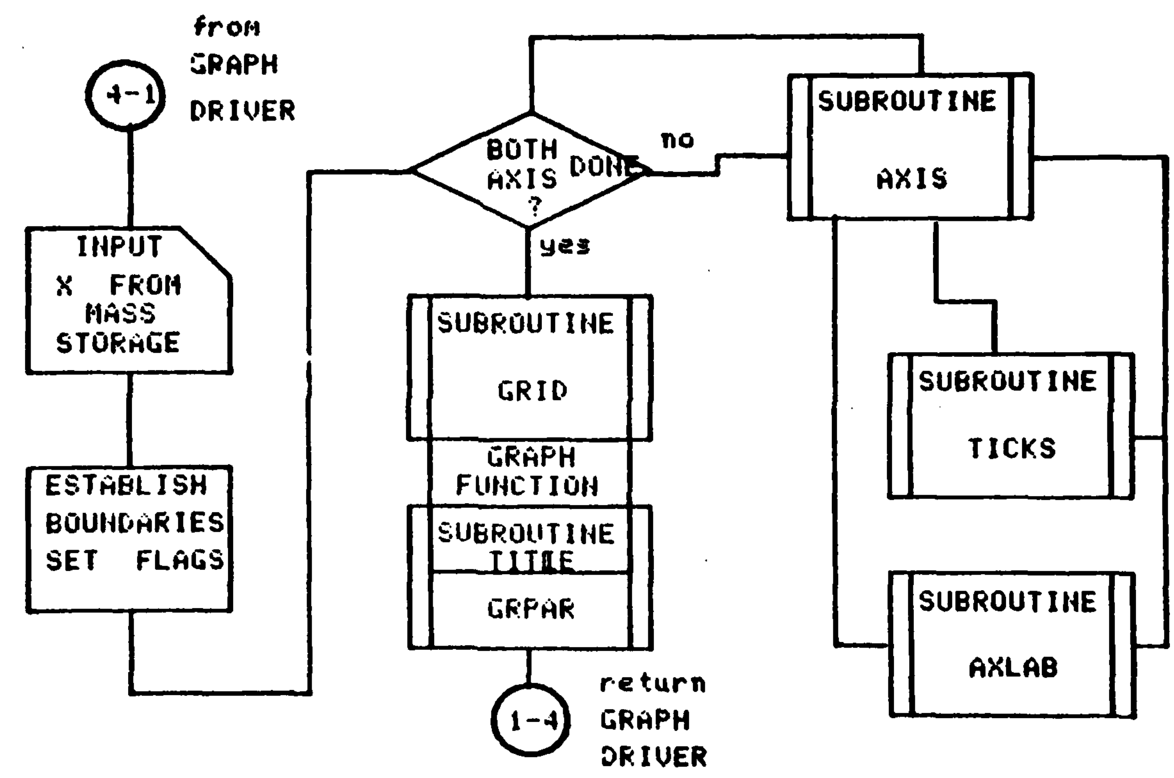


Figure 4.10. General Flow Diagram--Graphics Subroutine

The general description of graphic routines provided above is most typified by GRIN.

Two special notes need to be made. First, graphing begins with the ninth element of the array. This is to prevent the display of an erroneous spike input by the DPO. (These erroneous values have a minimal effect on the processing). Secondly, the function is graphed in discrete steps equal to 1/N of the total array value along the axis:

$$\text{Graphed Point} = (Q * Z1),\ X(Q) \qquad (4.13)$$

where: Q = array number

X(Q) = array element

The title of the graph is selected by the routine located in lines 5290-5380.

The horizontal dimenion for the graphic is time ie the vertical axis is scaled in volts.

g. Subroutine GRFOUR

This subroutine is also fairly typical of the general graphic method. It displays the magnitude and phase components of the spectral data in polar form for the Direct and Backscattered waveforms and for the impulse response of the target.

Only the first 60 elements of the magnitude array are graphed. Values beyond the first 60 are of a random nature due to the processing performed to derive the transforms. Spectral content much beyond 10 GHZ is, therefore, negligible. All values of the phase array are plotted, although the note concerning the randomness of the data is also applicable here.

GRFOUR is actually performed in two distinct operations. The first graphs the magnitude of the transform. The horizontal axis dimensions are converted to frequency from time by finding the frequency of each data point:

$$\text{Graphed Point} = Q/(Z1*257),\ X(Q) \tag{4.14}$$

The second operation graphs the transform phase. The horizontal axis dimensions are converted to radians:

$$\text{Graphed Point} = (Q*2\pi)/257,\ X(Q) \tag{4.15}$$

GRFOUR is programmed in lines 5500-6080. It is 10% of the total program.

h. GROP

GROP is the graphic that reproduces the shape representing the target. That is, the target shape based on physical optics principals and uncorrected for field effects induced by residual currents. It represents a two-dimensional cross-sectional area cut of the target. Therefore, only target length and height are shown.

This subroutine is constructed generally in the same format as the other graphic subroutines. One important difference is that a true one-to-one relationship must be established for the coordinate axis. However, before this is done, the metric dimensions of the target length must be bounded. This is done in lines 6210-6240. Note that the array B0, source for the shapes storage in MATH, has already been scaled for the metric dimension in the y-direction or amplitude. The x-dimension, or length, is scaled for metric measures in line 6220. This is accomplished by multiplying the time between samples by the total number of samples in the array representing the target. This value is then compensated by the averaging antenna parameter established in MATH, S5:

$$W2 = \frac{(Z)(L)(1.2x10^{10})(S5)}{Q} \tag{4.16}$$

where: Z = sampling time between single samples

L = measured length in number of samples

S5 = antenna length compensator

Q = low-pass filter compensator

Q is always one for zero optimization, or no low-pass filtering. It has effect only when optimization is performed, and is designed to compensate for the spreading of the target dimensions in the x-direction during filtering. Note also, that all defined targets are measured in inches. All outputs are scaled inches. It should be a relatively simple procedure to generalize the program to handle either metric or english units.

The next major difference between GROP and other graphic routines is that all graphing is done in GROP itself without calling AXIS or any other external formatting subroutine. As mentioned above, the important concept is to properly relate the co-ordinant axis on a true one-to-one plot. This is done is statements 6290-6360 and is called "axis scaling". Axis scaling is done in two steps. First the general x-axis scaling factor A0 is found. This is done in 6290 by dividing the maximum horizontal bounding UDU by the viewport established by the display:

$$A0 = (W2 - W1) / (V2-V1-5) \qquad (4.17)$$

This yields UDU's/GDU in the x-direction. The y-axis scaling factor A1 is then fixed to this value. The dimensions in the y-direction are then checked by the program in lines 6320 to ensure that "clipping" or windowing out of the data does not occur. This is necessary as the vertical viewing axis is only 62% that of the x-axis. If the y-dimension were more than 52% of the x-dimension, data would be lost during graphing. To prevent this, the x-axis values are fixed so that the maximum x-dimension will always be plotted. This is an effective reduction in the size of the total displayed shape. To retain the true one-to-one axis relationship, the y-direction dimensions must be reduced by a corresponding percentage. This reduction factor is computed in line 6330 and applied to the array in 6440. Note that in 6330 twice the maximum y-dimension is used. This is done because the graphic output produces the mirror image of a axisymmetric object while the array itself is single-sided.

Once scaling is established in statement 6380, the array is plotted. As data is graphed it must be dimensioned in english units, compensated for optimization effects, and compensated for any viewport clipping. This is done on a point-by-point basis in line 6410. Note that the array has already been totally dimensioned and compensated. It is in fact the plotting point which now must be taken into consideration. This compensated plotting point is returned in U1 and is used in drawing the graph. Finally, the mirror image of each point is graphed to produce a "true" image. A flow diagram for GROP is given in Figure 4.11.

i. Subroutine GRAMP

GRAMP graphs the time domain ramp response in lines 6600-6910. It comprises 5% of the program.

GRAMP is identical to GRIN in practically every detail. Note that the array X is multiplied by 1000 in line 6670. This converts array amplitudes to millivolts. GRIN also employs this conversion.

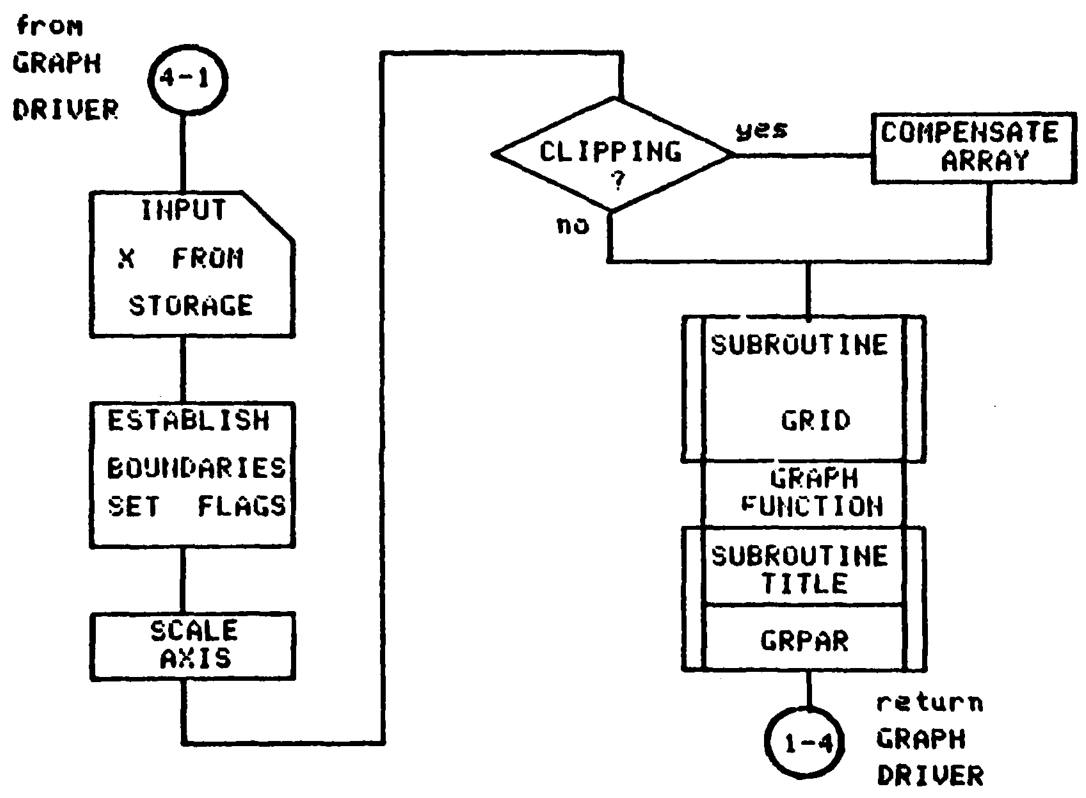


Figure 4.11. Flow Diagram--GROP

V. EXPERIMENTAL OBSERVATIONS

In this chapter, the results of several selected measurements will be presented. The observations made were chosen to demonstrate the flexibility of the Operating System as well as verify experimental results with the theoretical.

A. MEASUREMENT 1--VARY BORESIGHTED TARGET DISTANCE

1. Description of Setup

The purpose of this measurement is to observe what effect locating the target a distance different from the transmitting antenna then that specified for the receiving antenna, but maintaning the boresighted relationship of the antennas has on measurements taken by the OS. The receiving antenna is placed 2.54M from the transmitting antenna. The target is defined from the target library on Tape 2.

2. Results

The results are given in Figures 5.1 to 5.3 with the backscattered waveform, ramp response and physical optics shapes being presented.

The ramp response is seen to be typical for a cylinder although somewhat reduced in size. This is to be expected since the propagation attenuation losses are greater for the distance at which the target is located in this experiment than it is for the normal control case. With the distance taken into consideration by the Operating System software, it can be seen that the resultant physical optics shape is a close approximation. The target width (length) is within 10% of the true length and the diameter is 15.4% of the true diameter. The uncorrected width is 49% greater than the true length. The backscattered waveform shows the effect of some spreading in comparison to the control case and also displays a reduced S/N.

3. <u>Conclusions</u>

The distance between the receiving antenna and target can be arbitrary and the Operating System will be able to provide a reasonably accurate interpretation of the target. As the distance increases, this accuracy can be expected to decrease directly to the limit of the Systems ability to seperate the target and noise.

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         2  8-7-81   2.54M  1   1    LOCATION DIFFERENCE

MAXIMUM PEAK VALUE............    +1.68 mV

MINIMUM PEAK VALUE............    -1.48 mV

RMS VALUE.....................    +0.62 mV

MEAN VALUE....................     0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 50      OPTIMIZATION VALUE = 8
```

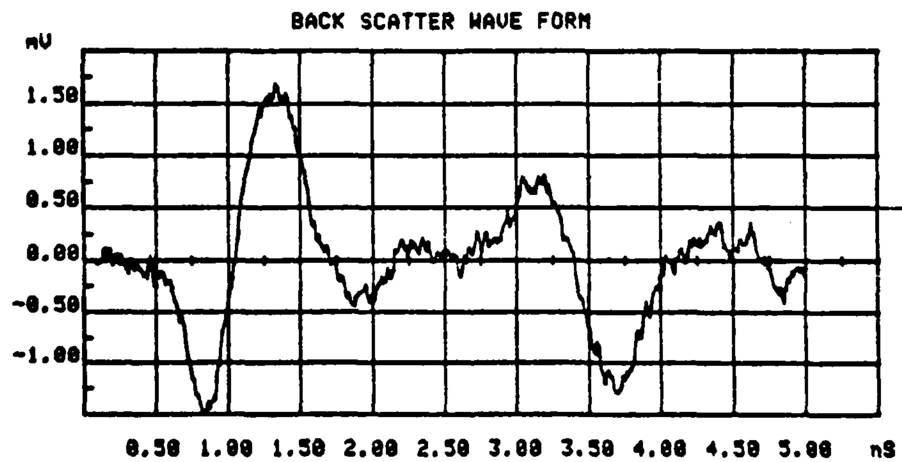


Figure 5.1. MEASUREMENT 1--Backscattered Waveform.

TARGET: RUN DATE DIST ANT TGT REMARKS
2 8-7-81 2.54M 1 1 LOCATION DIFFERENCE

MAXIMUM PEAK VALUE............ +6.86 mV-M

MINIMUM PEAK VALUE............ -196.33 mV-M

RMS VALUE..................... +112.76 mV-M

MEAN VALUE.................... -90.84 mV-M

NUMBER OF WAVEFORMS AVERAGED = 50 OPTIMIZATION VALUE = 0

RAMP RESPONSE -- TIME

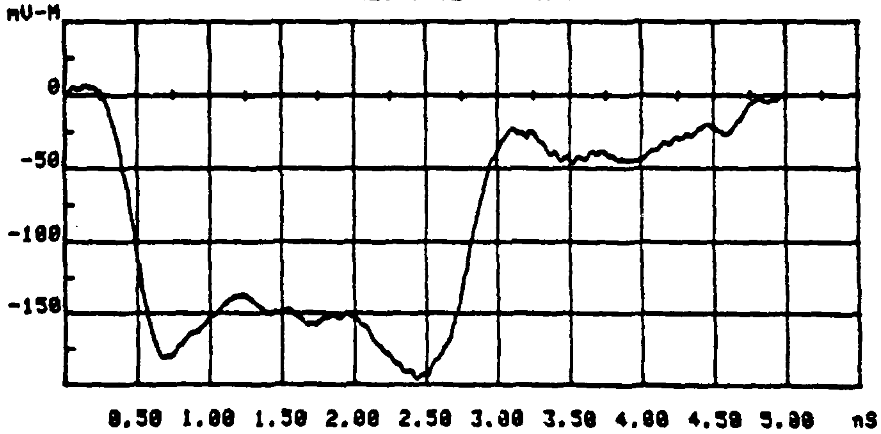


Figure 5.2. MEASUREMENT 1--Ramp Response

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
          2  8-7-81   2.54M  1   1    LOCATION DIFFERENCE
   DIAMETER (INCHES-CORRECTED)       6.9625 ( 6.0000)
   WIDTH (INCHES-CORRECTED)         13.2047 (12.0000)
   WIDTH (INCHES-UNCORRECTED)**     17.8711 (12.0000)
NUMBER OF WAVEFORMS AVERAGED = 50      OPTIMIZATION VALUE = 0
------------------------------------------------------------------
                RAMP RESPONSE -- PHYSICAL OPTICS
```

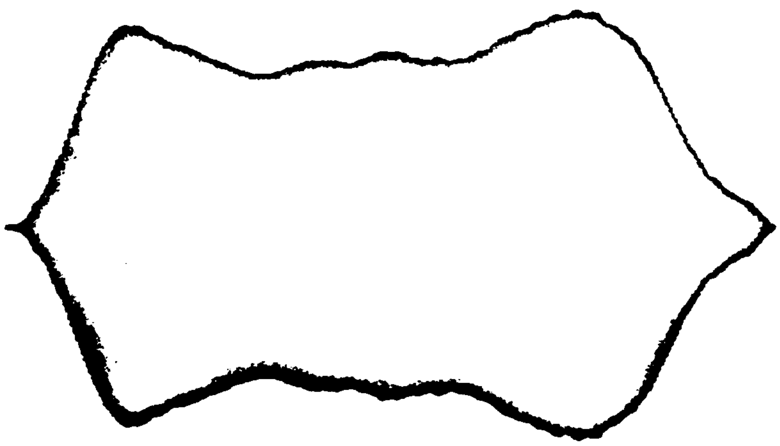


Figure 5.3. MEASUREMENT 1--Physical Optics Shape

B. MEASUREMENT 2--TARGET AND RECEIVING ANTENNA NOT BORESIGHTED

1. Description of Setup

An attempt is made to observe the effect of placing a target at an arbitrary location on the TDRL ground plane. The transmitted field is not axially incident on the target.

For this experiment, the target (cylinder 1) was placed 2.11 meters from the transmitting antenna and at a 90° angle (approximately) to the receiving/transmitting antenna axis. The receiving antenna is located in the control area of the TDRL. The target is at about a 60° angle to the receiving antenna and located 2.44 meters from it. The experimental setup is diagramed in Figure 5.4.

2. Results

The results are given in Figures 5.5 to 5.7 representing the ramp response, physical optics shape and backscattered waveform. Note that the distance input to the system is incorrect. The correct value as read from the DPO should be 1.57 meters. The diameter should be multiplied by the factor 1.53. Doing so yields a diameter of 6.3341 inches as the true corrected value. The resulting compensated values are thus very close to the targets actual dimensions. These figures may be suspect as subsequent runs

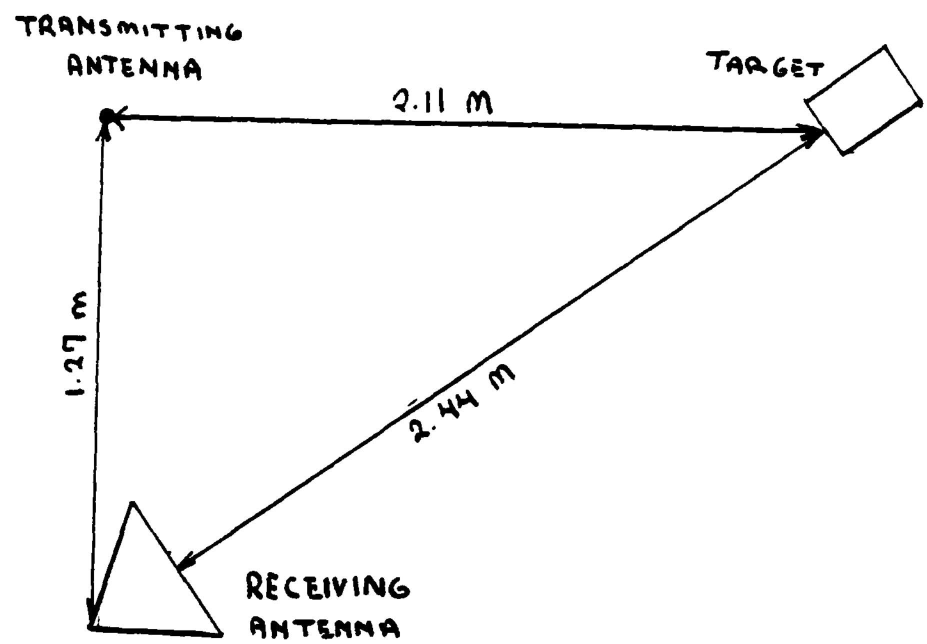


Figure 5.4. Measurement 2--Physical Setup

never yielded the same degree of accuracy, although they approached it. The important item is that the physical optics shape is a close approximation of that expected to be representative of a cylinder.

3. <u>Conclusions</u>

It would appear that the targets location can be generalized if the shape only and not the dimensions is the significant item of interest. However, time precluded further verification of this observation. It cannot be said with absolute certainty that this observation is completely general. Other configurations with the target located at different distances from the boresighted transmitting and receiving antennas should be observed. Note that for proper compensation for propagation attenuation, the distance the target is from the receiving antenna is determined by reading the DPO Distance Scale. This should be the OS distance input value vice the straight line measured distance from transmitting antenna to target.

TARGET: RUN DATE DIST ANT TGT REMARKS
3 8-7-81 1.27M 1 1 NOT BORESIGHTED

MAXIMUM PEAK VALUE............ +47.50 mV-M

MINIMUM PEAK VALUE............ -329.85 mV-M

RMS VALUE..................... +181.31 mV-M

MEAN VALUE.................... -133.88 mV-M

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0

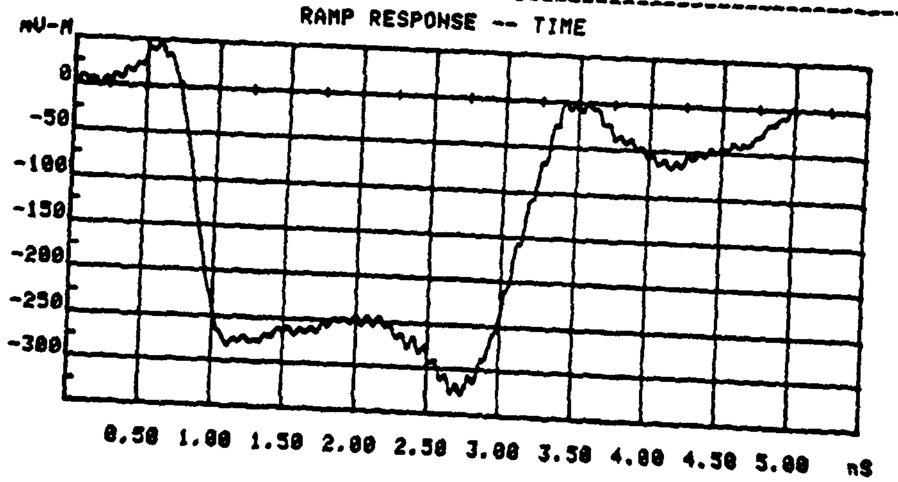


Figure 5.5. Measurement 2--Ramp Response

```
   TARGET: RUN DATE      DIST    ANT TGT  REMARKS
             3  8-7-81   1.27M   1   1    NOT BORESIGHTED
   DIAMETER (INCHES-CORRECTED)        4.1447 ( 6.0000)
   WIDTH (INCHES-CORRECTED)          11.8218 (12.0000)
   WIDTH (INCHES-UNCORRECTED)**      15.8789 (12.0000)
NUMBER OF WAVEFORMS AVERAGED = 4      OPTIMIZATION VALUE = 0
```

RAMP RESPONSE -- PHYSICAL OPTICS

Figure 5.6. Measurement 2--Physical Optics Shape

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         3  8-7-81   1.27M  1   1    NOT BORESIGHTED

MAXIMUM PEAK VALUE............    +2.40 mV

MINIMUM PEAK VALUE............    -2.49 mV

RMS VALUE.....................    +0.98 mV

MEAN VALUE....................     0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 4      OPTIMIZATION VALUE = 0
```

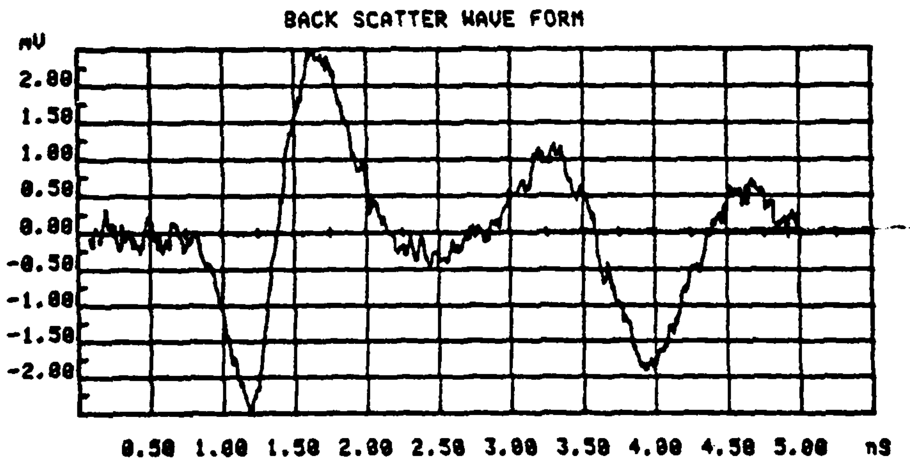


Figure 5.7. Measurement 2--Backscattered Waveform

C. MEASUREMENT 3--ANTENNA EFFECTS ON TARGET RESPONSES

1. Description of Setup

The purpose of this measurement is to verify that the effects of the antenna are in fact deconvolved out during processing. Most previous runs have been performed using antenna 1 (TEM Horn). This measurement is performed using three different length monopole antennas. The antennas used were antenna 2 (see TABLE II) (85 mm monopole), antenna 8 (205 mm monopole) and antenna 12 (285 mm monopole). The target used was target 1 (see TABLE I). Both target and antenna were placed in the control locations, 1.27 meters from the transmitting antenna. 21-acquisitions were averaged for each run. The results obtained should be compared with those obtained previously for the TEM horn.

2. Results

The results are presented in Figures 5.7 to 5.24 Each antenna has the results of its run shown in six graphs. The first graph depicts the direct waveform as seen by the individual antenna, the second is the ramp response resulting, the third figure is the physical optics representation of the target shape, and the final three figures are the optimized frequency domain impulse, time domain impulse and ramp response for the target. Figure 5.7 to 5.12 are for monopole antenna 2. Figures 5.13 to 5.18 are for monopole antenna 8 and figures 5.19 to 5.24 are for monopole antenna 12.

The first obvious result is that in comparison of the ramp responses, the smaller the antenna is in relation to the target, the less typical is the ramp and, correspondingly, the physical optics shape. However, for antennas considerably taller than the height of the target, a significant amount of noise pollutes the ramp response. In comparing the target impulse responses, it can be seen that the exact opposite appears to be true. The most representative impulse is for the the shortest monopole. The frequency domain impulse graphs show that the longer monopoles accept a higer frequency content than the shortest monopole.

3. Conclusions

First, the closer the antenna is to natural resonance with the incident pulse, the more faithful appears the resulting impulse response to theory. But it does not naturally follow that the corresponding ramp response will be as true a repsentation. The opposite appears to be true. It may be that the short antenna is shadowed by a portion of the target. More likely, the short antenna is just not large enough to accept the full radiated backscatter of the target. Conversely, the 285-mm monopole is sensitive to environmental noise. As can be seen in figures 5.20 and 5.14, the ramp responses display the relatively greater sensitivity of the 285-mm monopole to environmental noise than the 205-mm monopole. Although the observation is limited to just these runs, it may be possibly concluded that there is a "best" monopole antenna length for a particular target size.

In conclusion, it can be said that the effects of the antenna are in general deconvolved out. However, other effects indirectly related to the target/antenna configuration may introduce factors which materially effect the reproduction of the target shape and its overall responses.

TARGET: RUN DATE DIST ANT TGT REMARKS
13 8-11-81 1.27M 2 1 DIPOLE ANTENNA #2(85MM)

MAXIMUM PEAK VALUE............ +76.81 mV

MINIMUM PEAK VALUE............ -91.83 mV

RMS VALUE..................... +31.88 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

DIRECT WAVEFORM

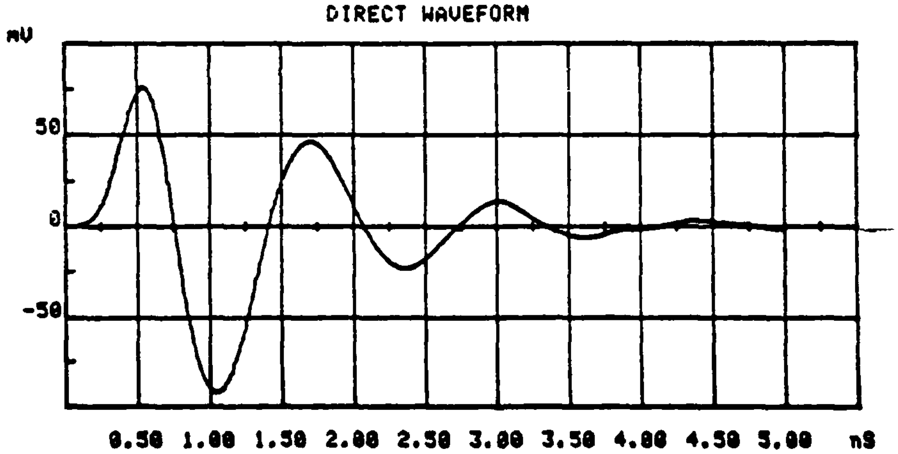


Figure 5.8. Measurement 3--Direct Waveform (85 mm)

```
TARGET: RUN DATE      DIST   ANT TGT  REMARKS
         13 8-11-81  1.27M  2   1    DIPOLE ANTENNA #2(85MM)

MAXIMUM PEAK VALUE............  +782.43 mV-M

MINIMUM PEAK VALUE............  -508.93 mV-M

RMS VALUE.....................  +374.80 mV-M

MEAN VALUE....................  +163.01 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
```

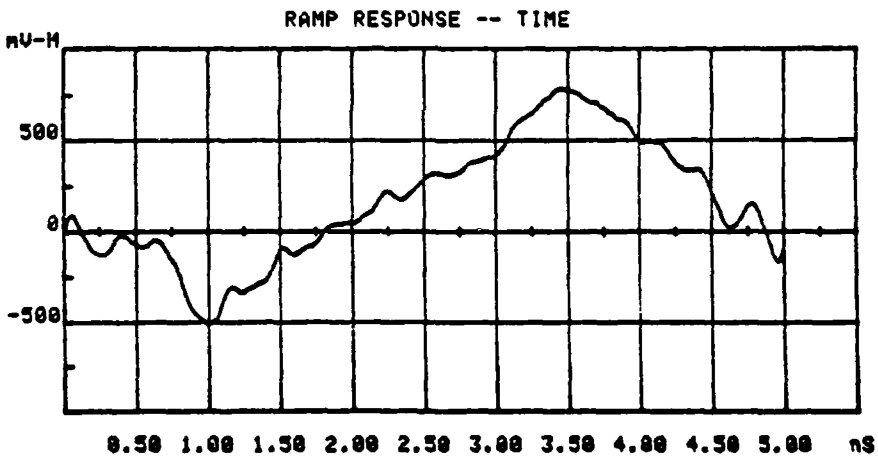


Figure 5.9. Measurement 3--Ramp Response (85 mm)

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
        13 8-11-81  1.27M  2   1    DIPOLE ANTENNA #2(85MM)
DIAMETER (INCHES-CORRECTED)       6.6879 ( 6.0000)
WIDTH (INCHES-CORRECTED)         12.5283 (12.0000)
WIDTH (INCHES-UNCORRECTED)**     10.1367 (12.0000)
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
------------------------------------------------------------------
                 RAMP RESPONSE -- PHYSICAL OPTICS
```

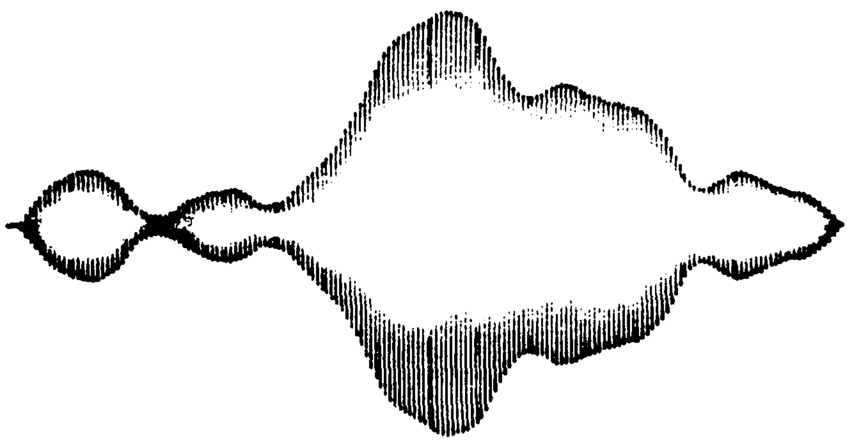


Figure 5.10. Measurement 3--Physical Optics Shape (85 mm)

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
        13 8-11-81  1.27M   2   1    DIPOLE ANTENNA #2(85MM)

MAXIMUM PEAK VALUE............  0.0008 mV

MINIMUM PEAK VALUE............ -0.0007 mV

RMS VALUE.....................  0.0002 mV

MEAN VALUE....................  0.0000 mV
NUMBER OF WAVEFORMS AVERAGED = 21     OPTIMIZATION VALUE = 0.5
```

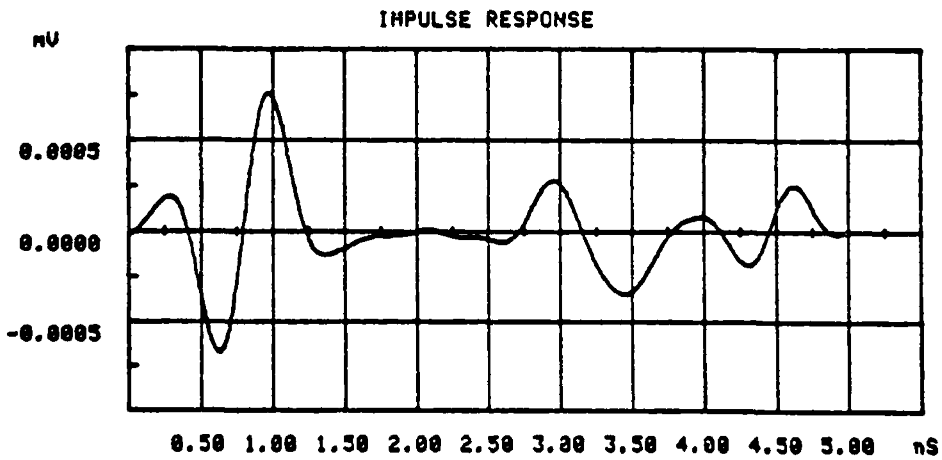
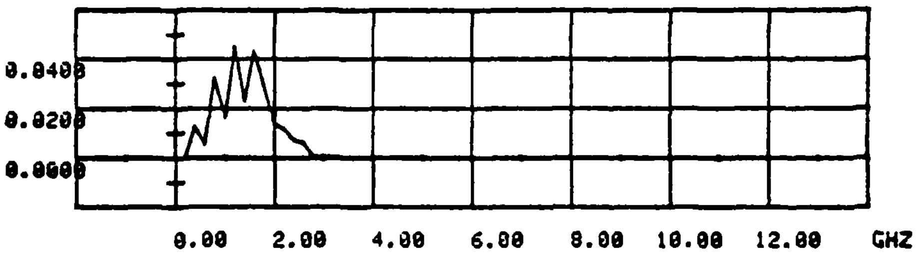


Figure 5.11. Measurement 3--Time-Domain Impulse Response (85 mm)

TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
13	8-11-81	1.27M	2	1	DIPOLE ANTENNA #2(85MM)

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

IMPULSE FFT--MAGNITUDE



IMPULSE FFT--PHASE

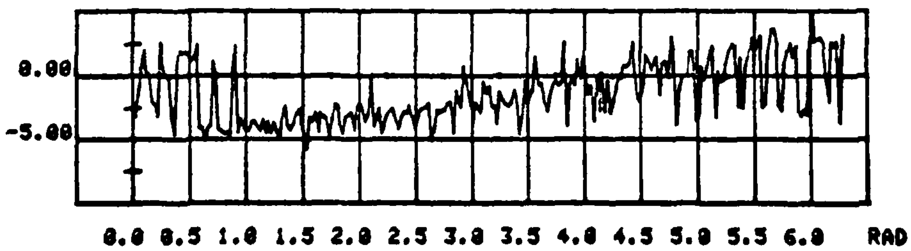


Figure 5.12. Measurement 3--Frequency-Domain Impulse Response (85 mm)

TARGET: RUN DATE DIST ANT TGT REMARKS
13 8-11-81 1.27M 2 1 DIPOLE ANTENNA #2(85MM)

MAXIMUM PEAK VALUE............ +613.71 mV-M

MINIMUM PEAK VALUE............ -345.20 mV-M

RMS VALUE..................... +284.65 mV-M

MEAN VALUE.................... +141.70 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

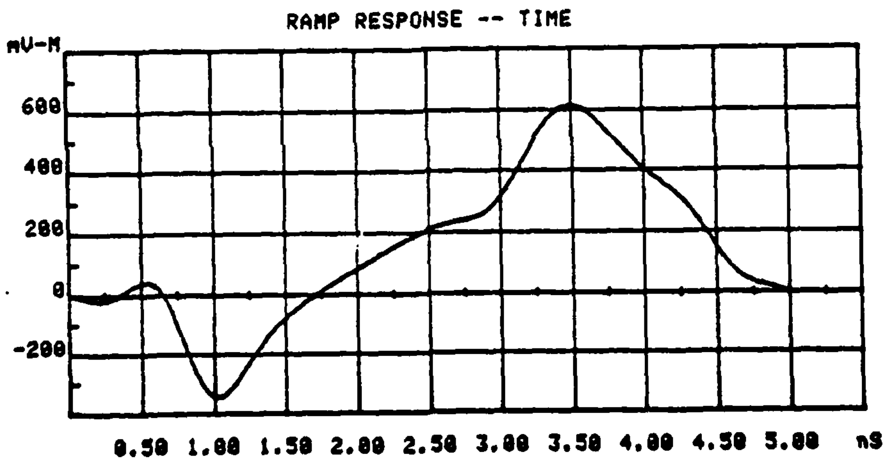


Figure 5.13. Measurement 3--Ramp Optimized (85 mm)

```
TARGET: RUN DATE      DIST    ANT TGT  REMARKS
         14 8-11-81   1.27M   8   1    DIPOLE ANTENNA #8 (205MM)

MAXIMUM PEAK VALUE............  +104.92 mV

MINIMUM PEAK VALUE............  -116.61 mV

RMS VALUE.....................   +59.50 mV

MEAN VALUE....................     0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
```

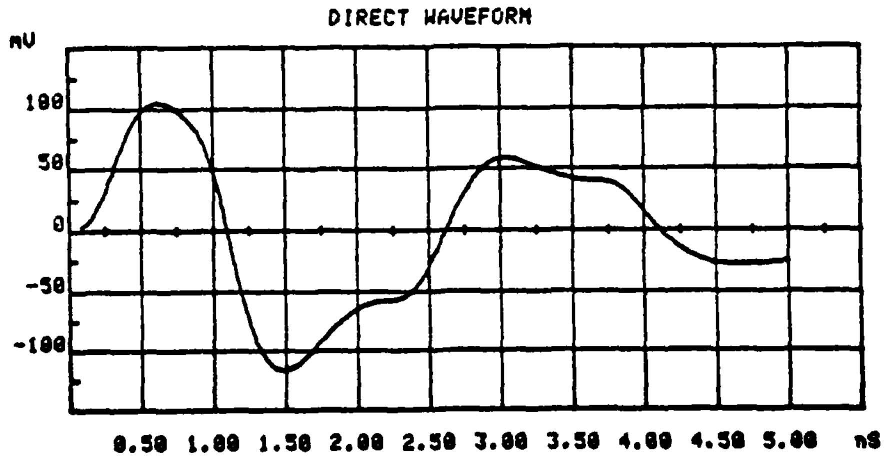


Figure 5.14. Measurement 3--Direct Waveform (205 mm)

TARGET: RUN DATE DIST ANT TGT REMARKS
14 8-11-91 1.27M 8 1 DIPOLE ANTENNA #8 (205MM)

MAXIMUM PEAK VALUE............ +5.93 mV-M

MINIMUM PEAK VALUE............ -609.89 mV-M

RMS VALUE..................... +357.09 mV-M

MEAN VALUE.................... -299.54 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

RAMP RESPONSE -- TIME

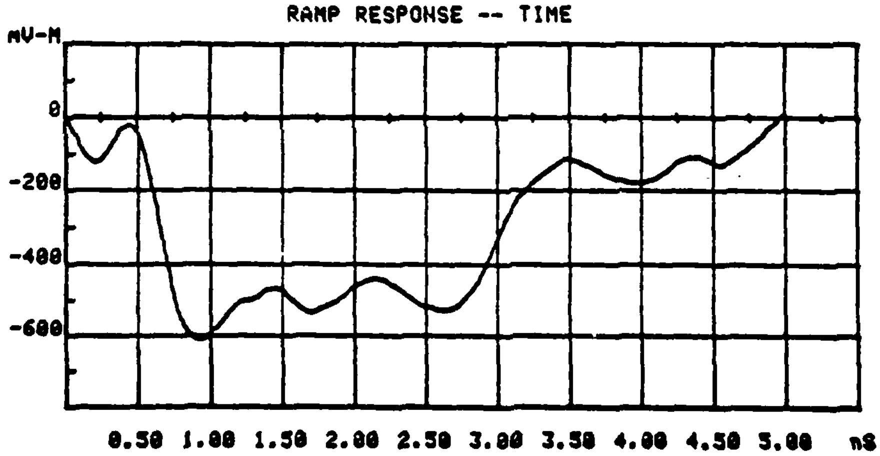


Figure 5.15. Measurement 3--Ramp Response (205 mm)

```
TARGET: RUN DATE      DIST   ANT TGT  REMARKS
        14 8-11-81  1.27M  8   1    DIPOLE ANTENNA #8 (205MM)
  DIAMETER (INCHES-CORRECTED)      5.8341 ( 6.0000)
  WIDTH (INCHES-CORRECTED)        12.0734 (12.0000)
  WIDTH (INCHES-UNCORRECTED)**    19.3945 (12.0000)
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
-------------------------------------------------------------
                RAMP RESPONSE -- PHYSICAL OPTICS
```

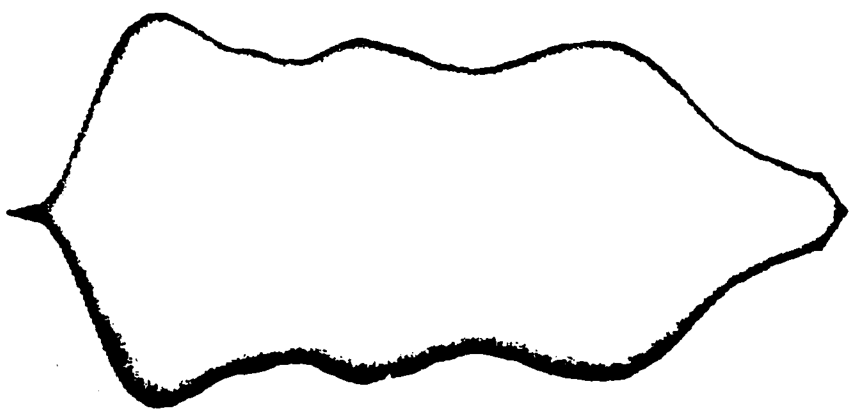


Figure 5.16. Measurement 3--Physical Optics Shape (205 mm)

```
TARGET: RUN DATE      DIST   ANT TGT  REMARKS
        14  8-11-81   1.27M  8   1    DIPOLE ANTENNA #8 (205MM)

MAXIMUM PEAK VALUE............  0.0006 mV

MINIMUM PEAK VALUE............ -0.0006 mV

RMS VALUE.....................  0.0002 mV

MEAN VALUE....................  0.0000 mV
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0.5
```

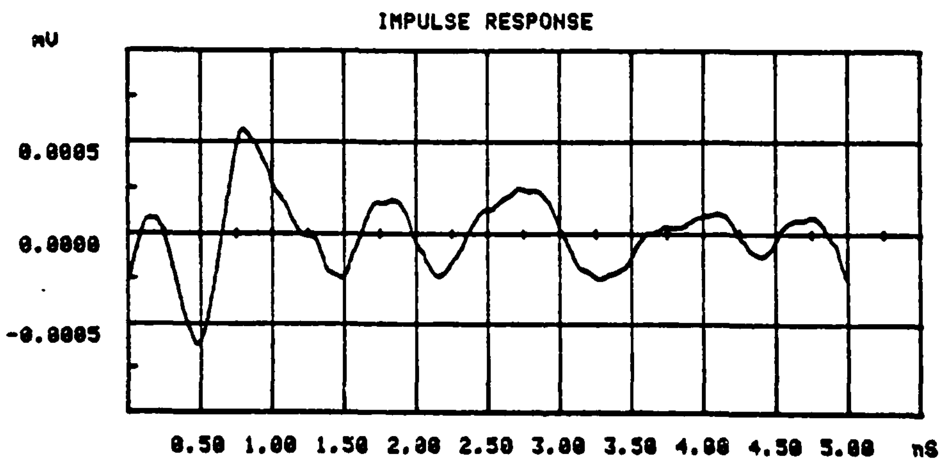
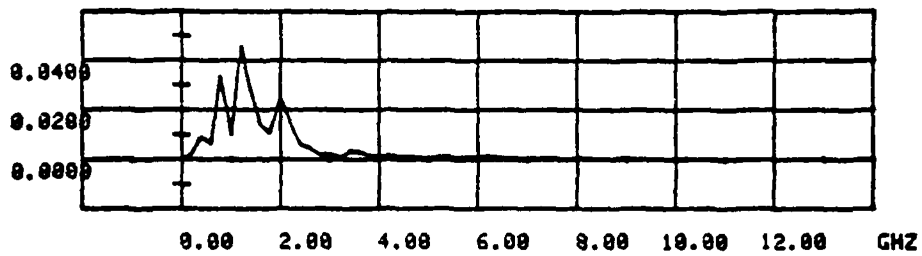


Figure 5.17. Measurement 3--Time-Domain Impulse Response (205 mm)

TARGET: RUN DATE   DIST   ANT TGT   REMARKS
14 8-11-81   1.27M   8   1   DIPOLE ANTENNA #8 (205MM)
NUMBER OF WAVEFORMS AVERAGED = 21   OPTIMIZATION VALUE = 0.5

IMPULSE FFT--MAGNITUDE



IMPULSE FFT--PHASE

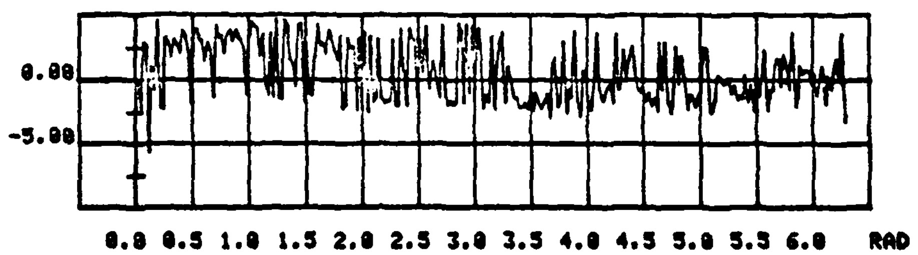


Figure 5.18. Measurement 3--Frequency-Domain Impulse Response (205 mm)

```
TARGET: RUN DATE      DIST   ANT TGT  REMARKS
          14 8-11-81  1.27M  8   1    DIPOLE ANTENNA #0 (205MM)

MAXIMUM PEAK VALUE............    +0.19 mV-M

MINIMUM PEAK VALUE............  -537.10 mV-M

RMS VALUE.....................  +318.08 mV-M

MEAN VALUE....................  -255.31 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0.5
```

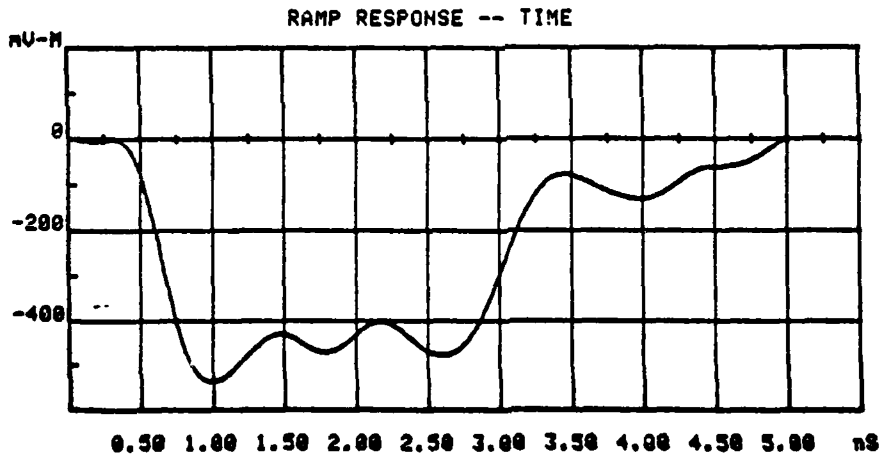


Figure 5.19. Measurement 3--Ramp Optimized (205 mm)

TARGET: RUN DATE DIST ANT TGT REMARKS
12 8-11-81 1.27M 12 1 DIPOLE ANTENNA #12(285MM)

MAXIMUM PEAK VALUE............ +101.31 mV

MINIMUM PEAK VALUE............ -122.78 mV

RMS VALUE..................... +67.52 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 8

DIRECT WAVEFORM

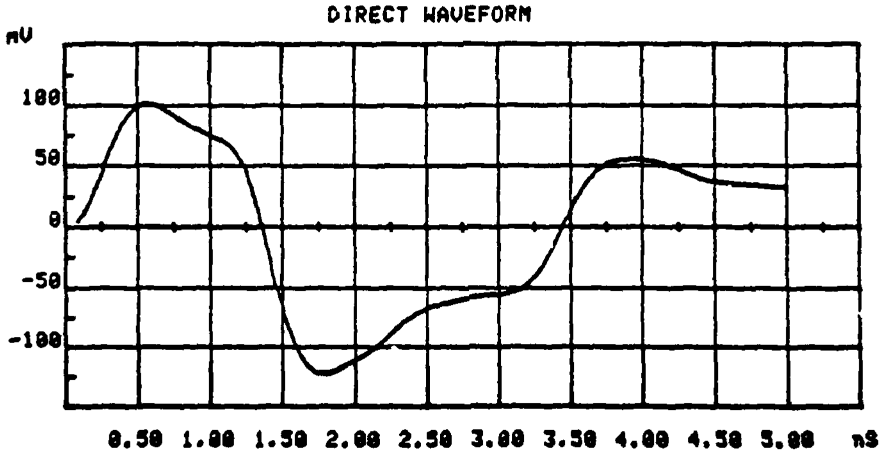


Figure 5.20. Measurement 3--Direct Waveform (285 mm)

TARGET: RUN DATE DIST ANT TGT REMARKS
12 8-11-81 1.27M 12 1 DIPOLE ANTENNA #12(285MM)

MAXIMUM PEAK VALUE............ +139.35 mV-M

MINIMUM PEAK VALUE............ -563.13 mV-M

RMS VALUE..................... +320.92 mV-M

MEAN VALUE.................... -252.72 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

RAMP RESPONSE -- TIME

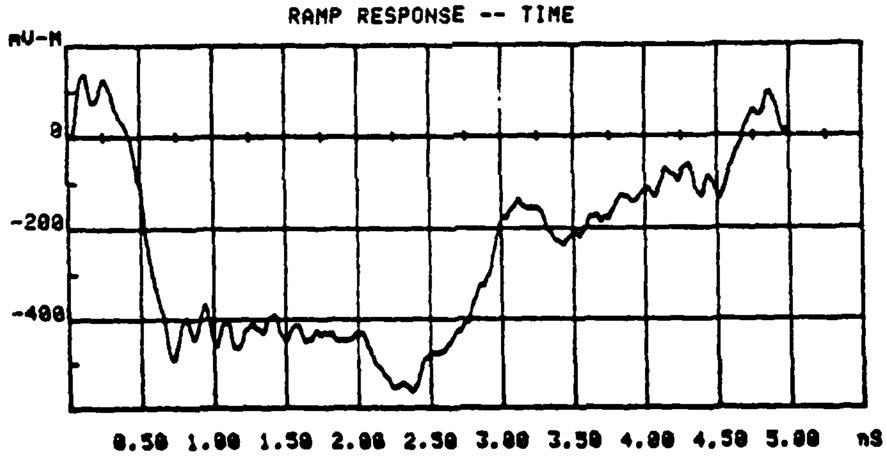


Figure 5.21. Measurement 3--Ramp Response (285 mm)

```
   TARGET: RUN DATE      DIST   ANT TGT  REMARKS
             12 8-11-81  1.27M  12  1    DIPOLE ANTENNA #12(285MM)
   DIAMETER (INCHES-CORRECTED)       6.0000 ( 6.0000)
   WIDTH (INCHES-CORRECTED)         12.0000 (12.0000)
   WIDTH (INCHES-UNCORRECTED)**     16.2305 (12.0000)
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
--------------------------------------------------------------------
                    RAMP RESPONSE -- PHYSICAL OPTICS
```

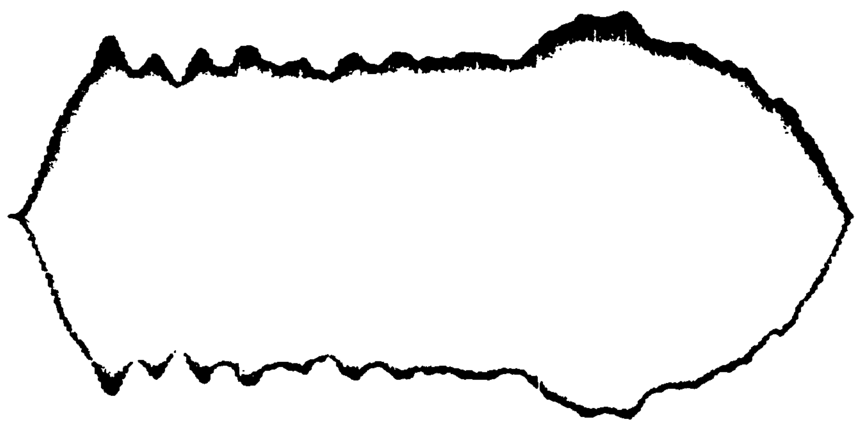


Figure 5.22. Measurement 3--Physical Optics Shape (285 mm)

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
         12 8-11-81  1.27M  12  1    DIPOLE ANTENNA #12(285MM)

MAXIMUM PEAK VALUE............  0.0006 mV

MINIMUM PEAK VALUE............ -0.0005 mV

RMS VALUE.....................  0.0002 mV

MEAN VALUE....................  0.0000 mV
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0.5
```

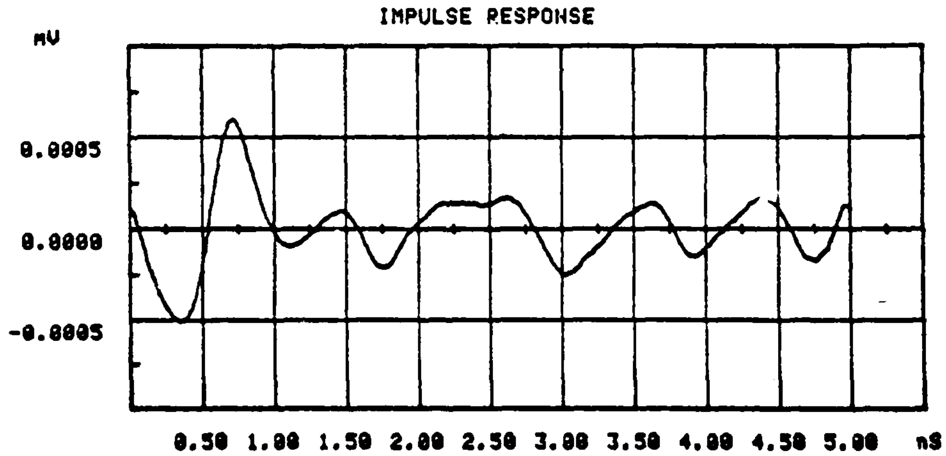


Figure 5.23. Measurement 3--Time-Domain Impulse Response (285 mm)

AD-A112 295 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 17/9

TIME DOMAIN RADAR LABORATORY OPERATING SYSTEM DEVELOPMENT AND T--ETC(U)

SEP 81 L A SORRENTINO

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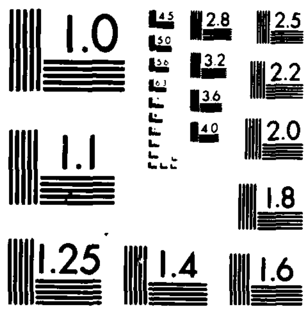
3 OF 4

AD A112295



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TARGET: RUN DATE DIST ANT TGT REMARKS
12 8-11-81 1.27M 12 1 DIPOLE ANTENNA #12(285MM)
NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

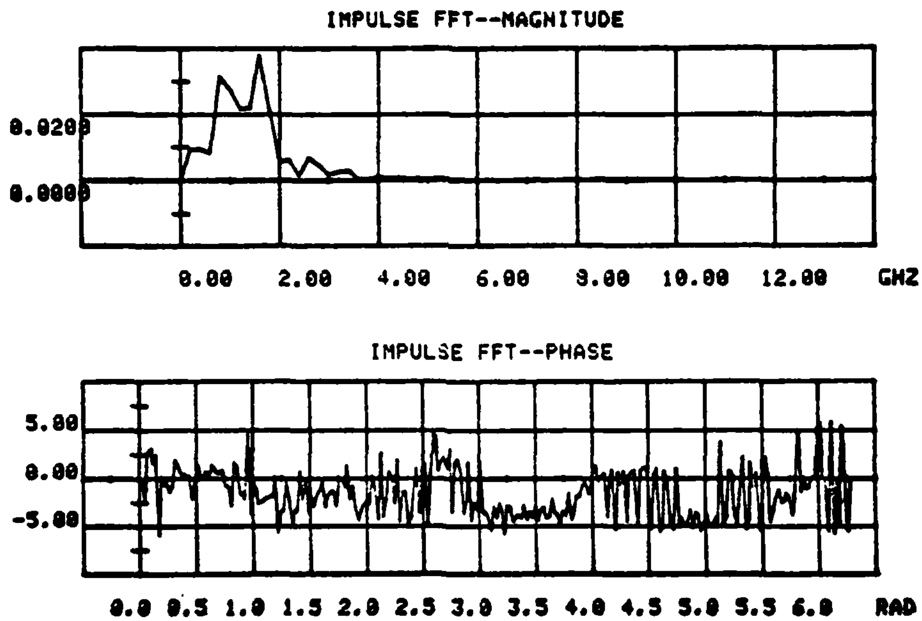


Figure 5.24. Measurement 3--Frequency-Domain Impulse Response (285 mm)

TARGET: RUN DATE DIST ANT TGT REMARKS
12 8-11-81 1.27M 12 1 DIPOLE ANTENNA #12(285MM)

MAXIMUM PEAK VALUE............ +28.80 mV-M

MINIMUM PEAK VALUE............ -596.67 mV-M

RMS VALUE..................... +368.85 mV-M

MEAN VALUE.................... -314.14 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

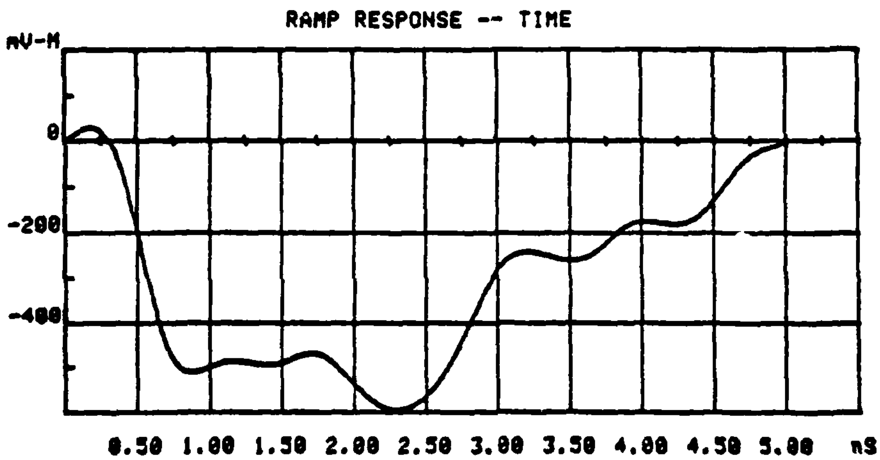


Figure 5.25. Measurement 3--Ramp Optimized (285 mm)

D. MEASUREMENT 4--ARBITRARY COMPOSITE TARGET

1. Description of Setup

This measurement was made to observe the response of the OS to a completely arbitrary, but axisymmetric target not encountered by the system previously. The composite target was a combination of target 11, a cone, and target 3, a cylinder. A drawing of the composite is given in Figure 5.25.

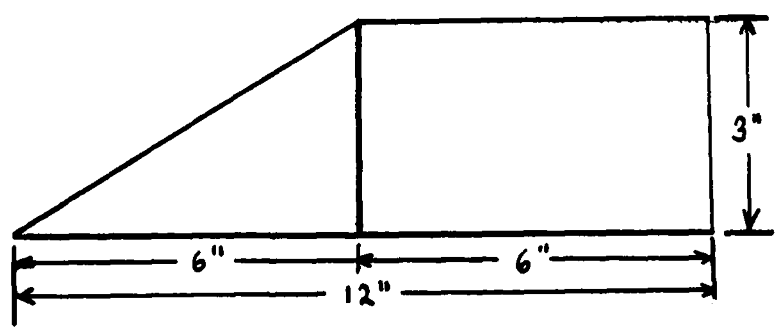


Figure 5.26. Measurement 4--Composite Targ

2. Results

The results are given in Figures 5.26 and 5.27, the physical optics shape and ramp responses respectively. The corrected diameter is 11% larger than actual, and the corrected length is 35% shorter than actual. The uncorrected length is 13% greater than actual. The shape is a close approximation of the targets actual shape, although somewhat shortened. The cone portion appears to be about one-half of the the total figure, as it was in the actual target.

3. Conclusions

Based on this observation and the many others taken during the implementation of the OS, it can be said that the OS can be relyed upon to produce recognizable representative shapes for known or unknown axisymmetric metallic targets.

TARGET: RUN DATE   DIST   ANT TGT REMARKS
27 9-11-81 1.27M 1   ??? COMPOSITE ARBITRARY TARGET
DIAMETER (INCHES-CORRECTED)   6.6669 (0.0000)
WIDTH (INCHES-CORRECTED)   8.9084 (0.0000)
WIDTH (INCHES-UNCORRECTED)**   13.5352 (0.0000)
UMBER OF WAVEFORMS AVERAGED = 21   OPTIMIZATION VALUE = 8

RAMP RESPONSE -- PHYSICAL OPTICS

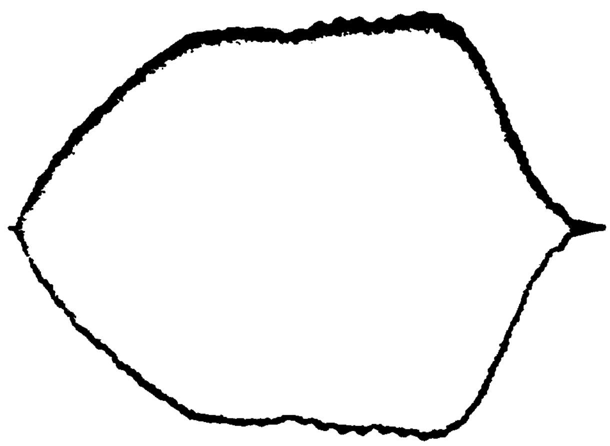


Figure 5.27. Measurement 4--Physical Optics Shape

TARGET: RUN DATE DIST ANT TGT REMARKS
27 8-11-81 1.27M 1 ??? COMPOSITE ARBITRARY TARGET

MAXIMUM PEAK VALUE............ +38.86 mV-M

MINIMUM PEAK VALUE............ -335.77 mV-M

RMS VALUE..................... +171.95 mV-M

MEAN VALUE.................... -115.28 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 8

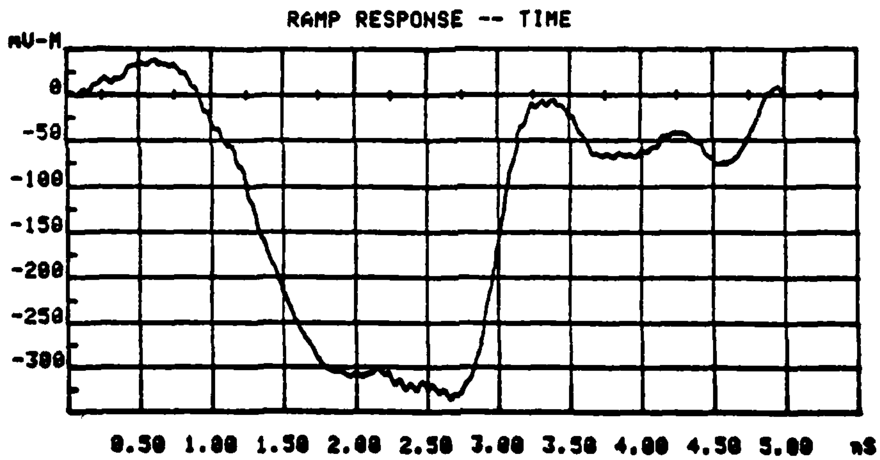


Figure 5.28. Measurement 4--Ramp Response

E. MEASUREMENT 5--DIELECTRIC CYLINDERS

1. Description of Setup

Two runs were made using different dielectric cylinders in place of metallic objects as targets. The dielectric cylinders used are similar in configuration to cylinder targets 2 and 3 machined from aluminum stock, but are made of plastic. For this measurement, the dielectric cylinders will refered to as target 2 and 3, respectively.

The purpose of the measurement was to observe the response of the dielectric cylinders to axially incident electromagnetic fields and to also see how the OS responds to a target which was non-metallic. The targets were placed in the standard control location, 1.27 meters from the transmitting antenna. The runs assumed the targets were of arbitrary, unknown shape for OS observation.

2. Results

Target 2 was run first. The results are given in Figures 5.28 to 5.31. The physical optics shape in Figure 5.28 is a very poor representation of the true targets shape. The reason for this can be observed in the ramp response of Figure 5.29. The S/N is extremely low. A noise spike at about 1.6 nsecs has caused the entire resultant shape to be foreshortened. The amplitude discrepancy can be attributed to the fact that the amplitude compensator was developed for the relatively large valued returns of the metallic cylinders. Nevertheless, when the ramp response is optimized, the general shape of the target can be seen as in Figure 5.30 and 5.31.

The results using Target 3 are shown in Figures 5.32 to 5.35. Because this target is physically larger than target 2, it has returned a substantially larger signal, large enough so that system noise is less of a significant factor (although still seen on the waveform). The amplitude is again much below that to be expected for a metallic target of similiar size.

3. Conclusions

Although the information provided by this measurement is limited, it appears that dielectric targets might provide returns which can be identified by time domain techniques. This could be an important area for more intensive research as the use of high density polymers and resins in real targets of interest is of growing importance to surveillance systems attempting to locate and identify such targets.

```
TARGET: RUN DATE     DIST    ANT TGT  REMARKS
         24 9-11-81  1.27M  1   ???  DIELECTRIC CYLINDER (3X12 IN)
DIAMETER (INCHES-CORRECTED)       0.7662 ( 0.0000)
WIDTH (INCHES-CORRECTED)          2.1596 ( 0.0000)
WIDTH (INCHES-UNCORRECTED)**      3.2813 ( 0.0000)
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
```

RAMP RESPONSE -- PHYSICAL OPTICS

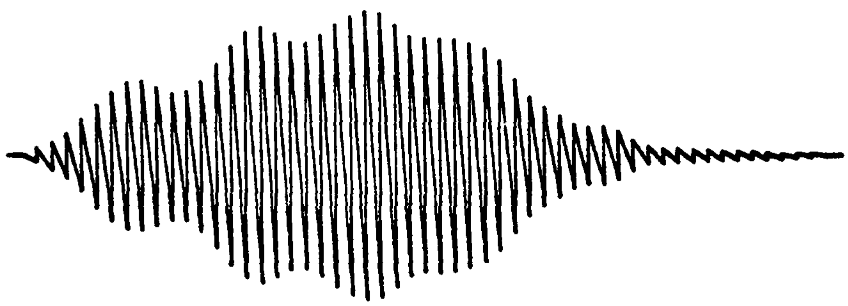


Figure 5.29. Measurement 5--Physical Optics (Target 2)

TARGET: RUN DATE DIST ANT TGT REMARKS
24 8-11-81 1.27M 1 ??? DIELECTRIC CYLINDER (3X12 IN)

MAXIMUM PEAK VALUE............ +11.15 mV-M

MINIMUM PEAK VALUE............ -38.59 mV-M

RMS VALUE..................... +17.07 mV-M

MEAN VALUE.................... -13.94 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 8

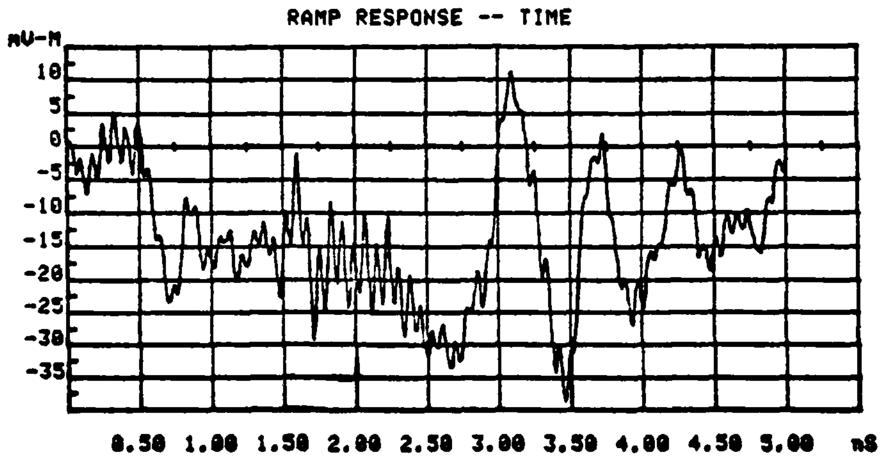


Figure 5.30. Measurement 5--Ramp Response (Target 2)

```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
        24 8-11-81  1.27M  1   ???  DIELECTRIC CYLINDER (3X12 IN)
  DIAMETER (INCHES-CORRECTED)       0.7662 ( 0.0000)
  WIDTH (INCHES-CORRECTED)          2.1596 ( 0.0000)
  WIDTH (INCHES-UNCORRECTED)**      9.0020 ( 0.0000)
NUMBER OF WAVEFORMS AVERAGED = 21     OPTIMIZATION VALUE = 1
-------------------------------------------------------------
                RAMP RESPONSE -- PHYSICAL OPTICS
```

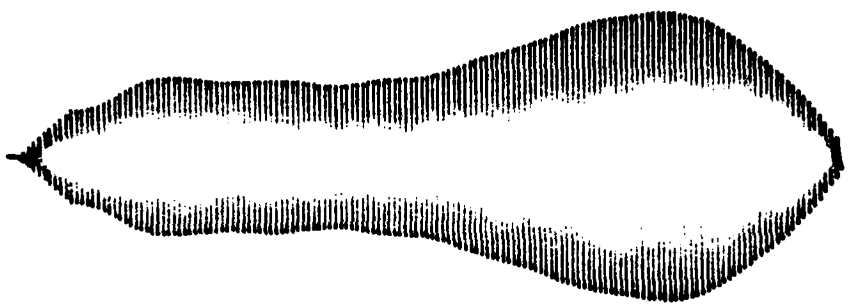


Figure 5.31. Measurement 5--Optimized Physical Optics (Target 2)

TARGET: RUN DATE DIST ANT TGT REMARKS
24 8-11-81 1.27M 1 ??? DIELECTRIC CYLINDER (3X12 IN)

MAXIMUM PEAK VALUE............ +8.29 mV-M

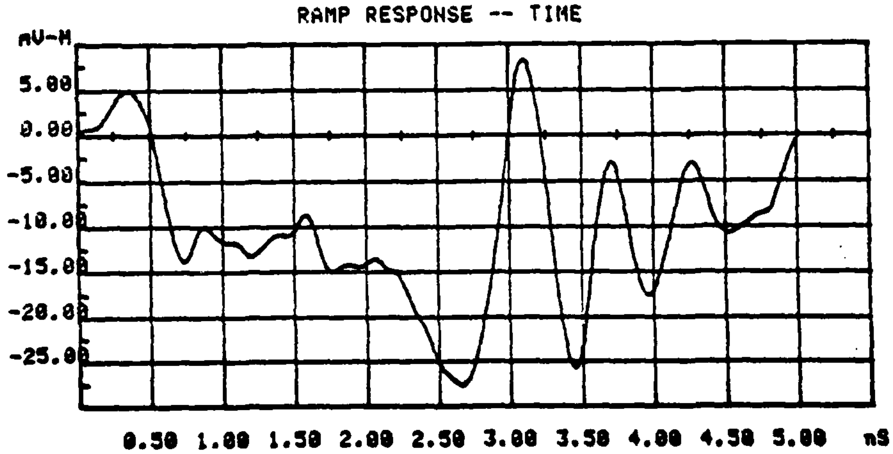
MINIMUM PEAK VALUE............ -27.71 mV-M

RMS VALUE..................... +13.28 mV-M

MEAN VALUE.................... -10.39 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 1

RAMP RESPONSE -- TIME



6

Figure 5.32. Measurement 5--Optimized Ramp (Target 2)

TARGET: RUN DATE DIST ANT TGT REMARKS

25 8-11-91 1.27M 1 ??? DIELECTRIC CYLINDER (6X6 IN)

DIAMETER (INCHES-CORRECTED) 1.4154 (0.0000)

WIDTH (INCHES-CORRECTED) 5.7075 (0.0000)

WIDTH (INCHES-UNCORRECTED)** 8.6719 (0.0000)

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

RAMP RESPONSE -- PHYSICAL OPTICS

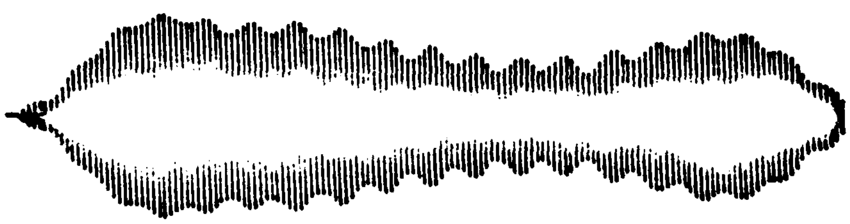


Figure 5.33. Measurement 5--Physical Optics (Target 3)

TARGET: RUN DATE DIST ANT TGT REMARKS

RUN	DATE	DIST	ANT	TGT	REMARKS
25	8-11-81	1.27M	1	???	DIELECTRIC CYLINDER (6X6 IN)

MAXIMUM PEAK VALUE............ +94.83 mV-M

MINIMUM PEAK VALUE............ -71.29 mV-M

RMS VALUE..................... +35.00 mV-M

MEAN VALUE.................... -3.50 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

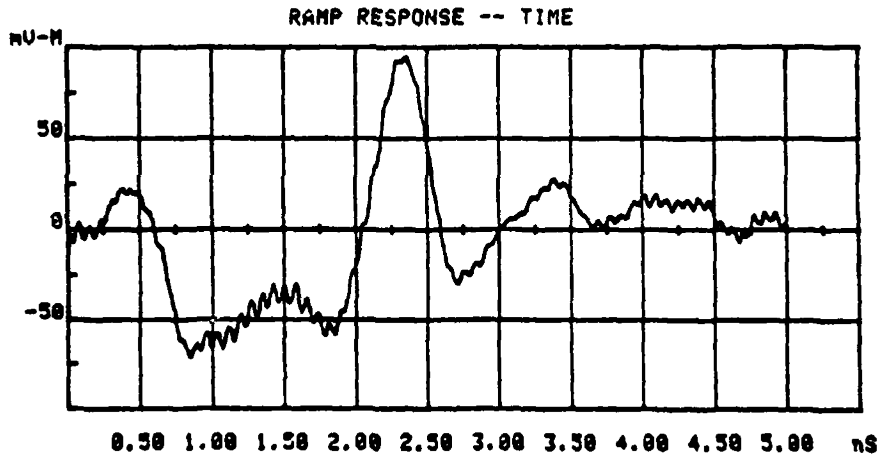


Figure 5.34. Measurement 5--Ramp Response (Target 3)

TARGET: RUN DATE DIST ANT TGT REMARKS
25 8-11-81 1.27M 1 ??? DIELECTRIC CYLINDER (6X6 IN)

MAXIMUM PEAK VALUE............ 0.0003 mV

MINIMUM PEAK VALUE............ -0.0004 mV

RMS VALUE..................... 0.0001 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

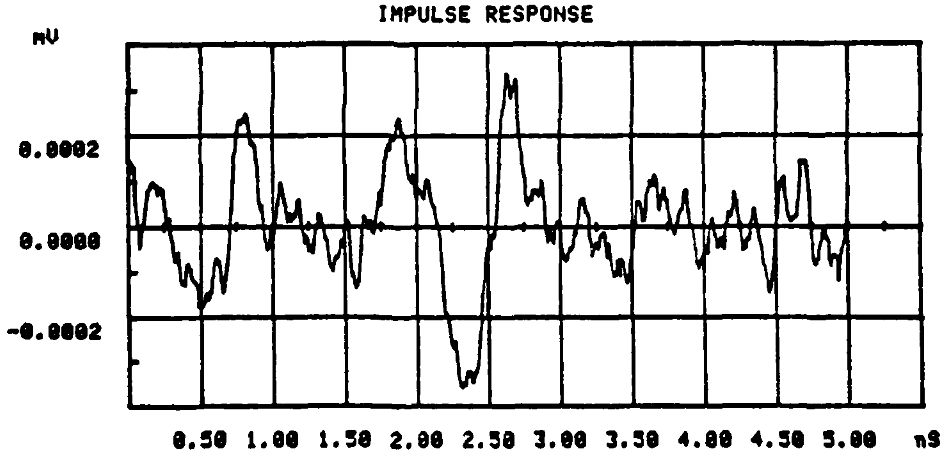
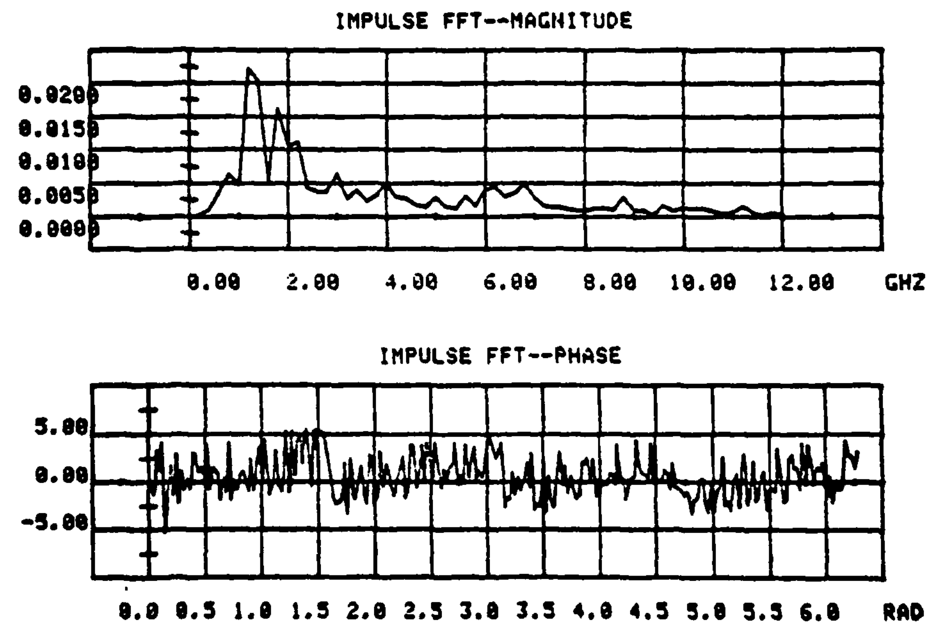


Figure 5.35. Measurement 5--Optimized Physical Optics (Target 3)

TARGET: RUN DATE DIST ANT TGT REMARKS
25 8-11-81 1.27M 1 ??? DIELECTRIC CYLINDER (6X6 IN)
NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5



6.35

Figure 5.36. Measurement 5--Optimized Ramp (Target 3)

VI. SUMMARY

A software Operating System has been developed for the Time Domain Radar Laboratory. The System has been designed to be relatively easy for inexperienced operators to use after an initial introduction to the OS code and the constituent hardware controlled. The OS extends the capability of the TDRL to the point where accurately processed transient time-domain data is presented in a form suitable for operator evaluation. The OS should serve as a primay research tool for the study of electromagnetic transients at the Naval Postgraduate School.

The OS is highly operator-processor interactive. Although the code that makes-up the OS is relatively complicated, its actual implementation and use is not difficult. There are numerous directives issued by the System and displayed on the Graphic Systems Crt to the operator requesting interactively the input of information through the GS keyboard at vital points in the programs.

The OS is composed of three subprograms. They are:

1. INPUT for the inputting of signal information from the TDRL ground plane

2. MATH for performing the significant mathematical computations for the OS

3. GRAPH for the presentation of the processed information in a form suitable for user evaluation and analysis

INPUT receives the desired signal in discrete digitized form from the systems Digital Processing Oscilloscope, the principal analog to digital converter used in the TDRL. The source signal is a rapid rise time gaussian pulse simulating an impulse. The acquired information is averaged a number of times as interactively requested by the operator. This is done to reduce the white gaussian noise content of the acquired analog signal.

MATH performs the Fourier conversion and signal deconvolution to determine the impulse response of the target. It also implements a noise reduction algorithm to optimize the processed data. The amount of optimization is under the control of the operator and is dependant on the degree to which loss of small surface features can be tolerated and yet obtain a good representation of the targets true shape and dimensions. The step and ramp responses are also obtained and stored for later evaluation. MATH determines the Physical Optics Shape of the target based on the ramp response uncorrected for the effects of induced currents on the body of the target. It further computes and applies compensation factors for length and width based on historically observed results from pre-defined targets. The compensators are applied directly to unknown targets resulting in an accuracy of 10% or better in determination of the true target dimensions.

GRAPH outputs the processed data to the GS CRT of the 4052 Graphic System. Information graphed includes the real time direct, incident, augmented and backscattered waveforms, the time-domain ramp response, physical optics shape of the target and the frequency domain spectral data for the direct and backscattered waveforms as well as the frequency domain impulse response. A means for inputting the optimization variable and for the return of program control to INPUT to acquire a new signal is also provided.

The total result is a highly versatile and powerful transient analysis tool. The OS has flexiblity in its internal organization to allow for future expansion and/or modification so as to allow the control of constituent hardware and software in applications involving other aspects of time-domain target identification. This is demonstrated in the complete integration of a Prony's Method

Hybrid Solution for the location of a targets poles and residues with the requirements for pure transient time-domain analysis procedures.

The code itself is complete as it stands. However, there are areas in which it could be made more efficient. Particularly, a number of graphic subroutines could be combined into one routine so as to reduce memory requirements. Also, a method for the display and selection of menu items using placement of the screen cursor to select the item might be developed. This would allow for the display of more information graphing processes than is now allowed.

One of the specialized algorithms developed for the OS is a method for expanding certain displayed graphs while retaining a true plot of relevant information. The result is that the GS has essentially infinite resolution and would allow for a close look at particular areas of the display without disturbing the true graph relationships. Although presently applied to only one subroutine in GRAPH, it could easily be adapted to any other graphic subroutine.

A second specialized routine is one whereby a true one-to-one relationship between coordinate axis is maintained. The unique feature of this algorithm is its generality in being applicable to any size data field on any size viewport without ever losing information due to "viewport clipping".

The results of field observations using the OS have proven remarkably faithful to theoretical results. However, the present use of the OS has been principally directed towards verifying that the system was up and working. As such, data was collected for axisymmetric targets almost exclusively as there was a large amount of literary support in this research area. There still is a need to explore system operation with this configuration of targets. In particular, the OS needs to be extended so as to be able to solve the Magnetic Field Integral Equation for EM transients on the surface of a target. This calculation would then be compared with field results to obtain a corrected and accurate representation of the target both in shape and dimension.

Hardware has proven very well suited to the needs of the TDRL. However, a monostatic antenna more directional than the present omnidirectional radiator presently used, may make the system more generally applicable. Improvements in reception by better match of the systems antenna components should allow for the determination of finer feature on smaller targets. A more rapid rise time generator having greater power outputs than presently supplied by the UHF impulse generator would be useful. Finally, a fully computerized analog digital processor with a microprocessor controlled sweep rate and distance windowing function would add much to the automation and, consequentially, consistancy of results in the TDRL.

This project is dynamic and holds promise for potentially practical applications of applied research. There remain many areas to explore by using the OS imaginatively. The system is now ready. The true need is for the refinement of procedures in using the OS and applying it to research areas having merit both instructive and practical.

APPENDIX A

DESCRIPTION OF PERIPHERAL GRAPHIC SYSEM ROM

As stated in Chapter IV, three peripheral ROM packs have been added to the Graphic System to tailor it to the specialized needs of the TDRL. They are the Signal Processing ROM Pack No. 1, the Signal Processing RCM Pack No. 2 (FFT) and the editor.

The Signal Processing ROM Packs provide fifteen mathmatical operations that are essential to advanced signal processing and data analysis. Signal processing is performed on waveforms or data stored in one-dimensionsal arrays. These capabilities do no alter the operation of the GS or occupy any of its avaliable RAM space. A summary of each ROM command follows. [Ref. 24 25]

A. Signal Processing ROM Pack No. 1

1. MAX -- finds the maximum of an array.
2. MIN -- finds the minimum of an array.
3. CROSS -- finds the location of a specified crossing level within an array

4. DIF2 -- performs a two-point differentiation of an array.

5. DIF3 -- performs a three-point differentiation of an array.

6. INT -- integrates an array.

7. DISP -- displays a graph of an array in raw form (without axis).

B. Signal Processing ROM Pack No. 2

1. FFT -- computes the fast Fourier transform of an array, placing the results in the same array.

2. IFT -- computes the inverse Fourier transform of an array, placing the results in the same array.

3. CONVL -- convolves two input arrays, placing the results in a third array.

4. CORR -- correlates two input arrays, placing the results in a third array.

5. POLAR -- converts an array of FFT data from rectangular form (reals and imaginaries) to polar form (magnitude and phase).

6. TAPER -- Multiplies an array by a cosine window of program-selectable tapering weights. When tapering is selected to be 50%, it provides a Hanning window.

7. UNLEAV -- sorts an array of interleaved FFT data into two arrays, one containing real and one containing imaginary components.

8. INLEAV -- interleaves the real and imaginary data from two input arrays into a third array whose format is acceptable to the IFT command.

The EDITOR is a ROM device that contains firmware routines that allow ASCII magnetic files to be altered or edited off-line. [Ref. 26]

APPENDIX B

GENERAL INFORMATION -- IDRL OPERATING SYSTEM

A. GRAPHING VARIABLES

The following named variables, numeric and constant, are used in more than one subprogram. A brief description of their purpose and the file in which they are initiated is given below. Note specific program/subroutine for local numeric variables, constants and arrays.

VARIABLE NAME	PURPOSE	FILE INITIATED
	STRING CONSTANTS	
E$	DATE OF RUN	2
F$	TARGET DISTANCE	2
G$	ANTENNA NUMBER	2
H$	TARGET NUMBER	2
M$	VERTICAL SCALE FACTOR - mVOLTS	2
P$	RUN NUMBER	2

VARIABLE NAME	PURPOSE	FILE INITIATED
R$	"RUN"	2
T$	HORIZONTAL SCALE FACTOR - SECONDS	2
X$	SPECIAL REMARKS	2
	NUMERIC CONSTANTS AND VARIABLES	
B6	OPTIMIZATION COMPENSATION	3
B7	OPTIMIZATION COMPENSATION	3
B8	OPTIMIZATION COMPENSATION	3
C5	TARGET LENGTH	2
C6	TARGET RADIUS	2
C7	ANTENNA PARAMETER AVERAGING VAL	2
L	OPTIMIZATION FACTOR	3,4
L1	FLAG	3
N2	SIGNALS AVERAGED/WAVEFORM	2
P7	FLAG	2
P8	RUN NUMBER	2

VARIABLE NAME	PURPOSE	FILE INITIATED
Q7	OPTIMIZATION COMPENSATION	3
Q9	ENDPOINT DISTANCES OPTICS	3
S1	MAG. TIME SCALE FACTOR	2
S4	FLAG	2
S5	ANTENNA PARAMETER-LENGTH	3
S6	ANTENNA PARAMETER-WIDTH	3
T1	DPO SWEEP	2
W	MISC CONSTANTS ARRAY	2,3
Z1	SAMPLING RATE DPO	2

APPENDIX C

LIST OF INPUT PROGRAM

A. GENERAL DESCRIPTION

1. Location: File 2

2. Memory space required (less mass storage): 24552-bytes

3. Maximum no. of steps: 272 (212 less remarks)

4. Description: INPUT provides the means to initialize and drive the TDRL Operating System. It allows input of all waveforms, averages acquisitions and stores data. It allows for input of antenna target parameters and initializes most graphing parameters. Inputs are from the keyboard of the GS, mass storage, and File 4. Output is to mass storage and File 3. This program is highly operator-processor interactive. Numerous messages and directives guide the user.

B. LOCAL PROGRAM VARIABLES AND CONSTANTS

1. Significant

TYPE	NAME	USE	REMARKS
ARRAY	B	DIWAV	(512)--TEMPORARY ARRAY FOR DIRECT WAVEFORM
ARRAY	C	AUGWAV	(512)--TEMPORARY ARRAY FOR AUGMENTED WAVEFORM
ARRAY	X0	ACAVG INWAV DIWAV AUGWAV SCATWAV	(512)--TEMPORARY ARRAY FOR SIGNAL ACQUISITION AND AVERAGING
CONSTANTS	P0	ALL	MENU ITEM

2. Miscellaneous

a. ARRAY: B0(512)

b. STRING CONSTANTS: A$, B$, C$, D$, J$, L$, K$
Z$, Y$

c. NUMERIC VARIABLES AND CONSTANTS: C1, C2, C3, C4, C5, I, M0, N, N1, P9, S0, T, X

C. MEMORY REQUIREMENTS

1. 4052 Internal Data Storage

DESCRIPTION	BYTES
EACH ACQUIRED WAVEFORM TO BE AVERAGED	4114
AUGMENTED WAVEFORM ARRAY	4114
DIRECT WAVEFORM ARRAY	4114
VARIOUS NUMERIC/STRING VARIABLES AND CONSTANTS	5575
TOTAL	17917
MAXIMUM MEMORY REQUIREMENTS (INTERNAL) FOR INPUT	42469

2. External Mass Storage Requirements (Data Tape)

DESCRIPTION	BYTES	FILE #
DIRECT WAVEFORM ARRAY	4114	50
INCIDENT WAVEFORM ARRAY	4114	51
AUGMENTED WAVEFORM ARRAY	4114	52
BACKSCATTERED WAVEFORM ARRAY	4114	53
TOTAL	16456	

D. SUBROUTINES

CLASS	NAME	LINE	STEPS	%	DESCRIPTION
DRIVER	DRIVER	100-1380	129	40	INITIALIZE AND DRIVE PROGRAM. PASS CONTROL TO NEXT FILE
INPUT	ACAVG	2000-2730	74	23	ACQUIRES, STORES AND AVERAGES DIWAV, INWAV, AUGWAV INPUTS
INPUT	INWAV	3000-3170	18 19	6 6	INITIALIZES INPUTS. STORES INCIDENT WAVE
INPUT	DIWAV	3200-3380	19	6	INITIALIZES, INPUTS, STORES DIRECT WAVE
INPUT	AUGWAV	3400-3590	20	6	INITIALIZES, INPUTS, STORES AUGMENTED WAVE
INPUT	SCATWAV	3600 3680	9	3	INPUTS TARGET SCATTER FROM DIFF. OF INWAV - AUGWAV. STORES DATA

CLASS	NAME	LINE	STEPS	%	DESCRIPTION
SPECIAL	ANTLOC	4000-4060	7	2	INPUTS ANTENNA PARA. FROM MASS STORAGE
SPECIAL	TGTLOC	4100-4160	7	2	TARGET DIMENSIONS (IF KNOWN) FROM MASS STORAGE
SPECIAL	NEWPAR	4200-4330	4	1	INITIALIZES ANTIN AND TGTIN FOR STORAGE OF NEW ANTENNA AND TARGET PARAMETERS
SPECIAL	ANTIN	4400-4600	21	7	INPUTS NEW ANTENNA PARA. TO MASS STORAGE
SPECIAL	TGTIN	4700-4800	11	3	INPUTS NEW TARGET PARA. TO MASS STORAGE

```
100 REM:::::::::::::::::::::::::::::::::::::::::::::::::::
110 REM:::::: FILE 2 ::::: INPUT ::::::: 7-28-81 ::::::::::::::::
120 REM:::::::::::::::::::::::::::::::::::::::::::::::::::
130 INIT
140 ON SRQ THEN 150
150 POLL N,N1;1
170 P8=0
180 PAGE
181 P7=0
190 G=0
200 S4=1
210 P8=P8+1
230 IMAGE 15X,45A
240 R$="RUN"
250 P$=STR(P8)
260 IMAGE 7A,8X,40A
270 P9=1
280 C$="ENTER THE NUMBER OF WAVEFORMS TO BE AVERAGED. N= "
290 D$="NUMBER OF WAVEFORMS TO BE AVERAGED= "
300 DIM B(512),C(512),X0(512),B0(512),W(8)
310 PAGE
320 PRINT USING 230:"DPO WAVEFORM AVERAGING"
330 PRINT
340 PRINT USING 260:"PROGRAM","TITLE"
350 PRINT
360 PRINT USING 260:"1","DIRECT WAVEFORM"
370 PRINT
380 PRINT USING 260:"2","INCIDENT WAVEFORM"
390 PRINT
400 PRINT USING 260:"3","AUGMENTED WAVEFORM"
410 PRINT
420 PRINT USING 260:"4","INPUT NEW TARGET"
430 PRINT
440 PRINT USING 260:"5","INPUT NEW ANTENNA."
```

```
450 PRINT
460 PRINT USING 260:"6","DATA TO INVERSE SCATTERING ALGORITHM"
470 PRINT
480 PRINT USING 260:"7","DATA TO SEM ALOGORITHM"
490 PRINT
500 PRINT USING 260:"8","NO FURTHER PROCESSING DESIRED.  END."
510 PRINT
520 PRINT USING 230:"ENTER THE PROGRAM NUMBER YOU WANT AND RETURN."
530 INPUT P0
540 PAGE
550 IF P0=>4 THEN 1090
560 IF P9<>1 THEN 1090
570 IF P8<>1 THEN 660
580 REM::::::::::::: select sweep rate on DPO for INPUT program :::::
590 PRINT "SET SWEEP SCAN ON DPO.  INPUT SCAN TIME IN SECONDS BY"
600 PRINT
610 PRINT "TYPING IN THE VALUE AT THE END OF THIS LINE.  SWEEP TIME = ";
640 INPUT T1
650 PRINT
660 IF P8=1 THEN 850
670 PRINT "DO YOU WANT TO CHANGE DISTANCE PARAMETER? TYPE Y=YES,";
680 PRINT "N=NO."
690 INPUT Y$
700 IF Y$<>"Y" THEN 730
710 PRINT "NEW DISTANCE = ";
720 INPUT F$
730 PRINT "DO YOU WANT TO CHANGE ANTENNA TYPE? TYPE Y=YES, N=NO."
740 INPUT Y$
750 IF Y$<>"Y" THEN 780
760 PRINT "NEW ANTENNA # = ";
770 INPUT G$
780 GOSUB 4000
790 PRINT
800 PRINT "DO YOU WANT TO CHANGE TARGETS? TYPE Y=YES, N=N0."
810 INPUT Y$
```

```
820 IF Y$<>"Y" THEN 1000
830 PRINT "NEW TARGET (??? IF UNKNOWN): ";
840 GO TO 990
850 PRINT "INPUT FOLLOWING PARAMETERS"
860 PRINT
870 PRINT "DATE: ";
880 INPUT E$
890 PRINT "DISTANCE: ";
900 INPUT F$
910 PRINT "ANTENNA #: ";
920 INPUT G$
930 PRINT
940 GOSUB 4000
950 IF P8=1 THEN 980
960 PRINT
970 GO TO 800
980 PRINT "TARGET # (??? IF UNKNOWN): ";
990 INPUT H$
1000 IF H$<>"???" THEN 1040
1010 C5=0
1020 C6=0
1021 C7=A5(61)
1022 S5=A5(62)
1023 S6=A5(63)
1024 S5=S5/(C7-1)
1025 S6=S6/(C7-1)*(VAL(F$)/1.27)↑2
1026 DELETE A5
1030 GO TO 1050
1040 GOSUB 4100
1050 PRINT
1060 PRINT "BRIEFLY DESCRIBE RUN PURPOSE"
1070 INPUT X$
1080 P9=0
1090 GOSUB P0 OF 3000,3200,3400,1140,1110,3620,3620,1260
1100 GO TO P0 OF 280,280,280,280,280,1170,1170
```

```
1110 C1=1
1120 GOSUB 4200
1130 RETURN
1140 C1=2
1150 GOSUB 4200
1160 RETURN
1170 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
1180 REM::::: EXIT FROM INPUT TO MATH PROGRAM ::::::::::::::::::::::::
1190 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
1200 DELETE J$,L$,K$,Z$,B,C,X0,B0,S0,M0,T
1210 FIND 3
1220 CALL "LINK",100
1230 REM//////////////////////////////////////////////////////////////
1240 REM/////////////// END OF DRIVER ROUTINES /////////////////////
1250 REM//////////////////////////////////////////////////////////////
1260 END
2000 REM//////////////////////////////////////////////////////////////
2010 REM/////////////// BEGIN SUBROUTINES /////////////////////////
2020 REM//////////////////////////////////////////////////////////////
2030 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2040 REM:::::::::::::: SUBROUTINE---ACAVG ::::::::::::::::::::::::::::
2050 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2060 REM:::::::::::::: acquire and average signals thru DPO ::::::::::
2070 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2080 REM:::::::::::::: initialize subroutine :::::::::::::::::::::::::
2090 PRINT
2100 PRINT C$;
2110 INPUT N2
2120 PRINT
2130 PRINT D$;N2
2140 REM::::::::::: store and hold waveform in DPO ::::::::::::::::::
2150 W(8)=0
2160 FOR I=1 TO N2
2170 IF N2<21 THEN 2250
2180 IF N2<101 THEN 2210
```

```
2190 IF W(8)=9 THEN 2240
2200 GO TO 2220
2210 IF W(8)=4 THEN 2240
2220 W(8)=W(8)+1
2230 GO TO 2410
2240 W(8)=0
2250 K$="
2260 J$=STR(I)
2270 L$=J$&K$
2280 REM:::::::::::::: waveform count to DPO screen ::::::::::::::::::
2290 PRINT @1:"ADR ";3072
2300 PRINT @1:"SCL ";"WAVEFORM  "
2310 PRINT @1:"ADR ";7296
2320 PRINT @1:"OCT ";"040010"
2330 PRINT @1:"ADR ";3093
2340 PRINT @1:"SCL ";L$
2350 PRINT @1:"ADR ";7296
2360 PRINT @1:"OCT ";"040010"
2370 CALL "WAIT",1.5
2410 PRINT @1:"STO ";"A"
2420 CALL "WAIT",T1
2430 PRINT @1:"HOL ";"A"
2440 REM:::::::::::::: transfer waveform to 4052 and average :::::::::
2450 PRINT @1:"DPA?"
2460 INPUT @1:X0
2470 FOR J=1 TO 8
2480 IF X0(J)=>511 THEN 2500
2490 X0(J)=511
2500 NEXT J
2510 IF I>1 THEN 2530
2520 B0=0
2530 B0=B0+X0
2540 NEXT I
2550 X0=B0/N2
2560 X0=X0-511
```

```
2570 REM::::::::::::: waveform scaling from DPO to 4052 ::::::::::::
2580 PRINT @1:"CHL ";"A1"
2590 PRINT @1:"SCL?"
2600 INPUT @1:M$
2610 PRINT @1:"CHL ";"A2"
2620 PRINT @1:"SCL?"
2630 INPUT @1:T$
2631 REM::::::::::::: acquired wave scaling factors-amplitude :::::::
2640 S0=VAL(M$)
2650 M0=POS(M$,"V",1)
2660 Z$=SEG(M$,M0-1,1)
2670 M$=SEG(M$,M0-1,2)
2680 M0=POS("munp",Z$,1)
2690 V=S0*10↑(-3*M0)
2700 X0=X0*(V/102.3)
2710 REM::::::::::::: acquired wave scaling factors-time :::::::::::
2720 S1=VAL(T$)
2730 T=POS(T$,"S",1)
2740 Z$=SEG(T$,T-1,1)
2750 T=POS("munp",Z$,1)
2760 IF S1*10<1000 THEN 2800
2770 T$=SEG("munp",T-1,1)
2780 T$=T$&"S"
2790 GO TO 2820
2800 T$=SEG("munp",T,1)
2810 T$=T$&"S"
2820 Z1=S1*10↑(-3*T)/51.2
2830 RETURN
3000 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3010 REM::::::::::::: SUBROUTINE---DIWAV :::::::::::::::::::::::::::::
3020 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3030 REM::::::::::::: acquire incident wave and average N2 times ::::
3040 PAGE
3050 PRINT "YOU WILL NOW DETERMINE THE CONVOLVED IMPULSE RESPONSES OF"
3060 PRINT
```

```
3070 PRINT "THE TRANSMITTING AND RECEIVING ANTENNAs ONLY.  NO TARGET."
3080 PRINT
3090 PRINT "TRANSMIT ANTENNA MUST LIE ON THE RECEIVE ANTENNA BORESIGHT."
3100 PRINT
3110 PRINT "IS IMAGE PLANE SET-UP?  PRESS ""RETURN"" WHEN READY."
3120 INPUT B$
3130 GOSUB 2030
3140 FIND @22:50
3150 WRITE @22:X0
3160 PRINT "GGG"
3170 RETURN
3200 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3210 REM::::::::::::: SUBROUTINE---INWAV :::::::::::::::::::::::::::::
3220 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3230 REM::::::::::::: acquire direct wave and average N2 times ::::::
3240 PAGE
3250 PRINT "YOU WILL NOW DETERMINE THE CONVOLVED IMPULSE RESPONSES OF"
3260 PRINT
3270 PRINT "THE TRANSMITTING AND RECEIVING ANTENNAs WHEN THE RECEIVING"
3280 PRINT
3290 PRINT "ANTENNA IS NOT BORESIGHTED ON TRANSMITTER.  NO TARGET."
3300 PRINT
3310 PRINT "IS IMAGE PLANE SET-UP?  PRESS ""RETURN"" WHEN READY."
3320 INPUT B$
3330 GOSUB 2030
3340 B=X0
3350 FIND @22:51
3360 WRITE @22:X0
3370 PRINT "GGG"
3380 RETURN
3400 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3410 REM::::::::::::: SUBROUTINE---AUGWAV ::::::::::::::::::::::::::::
3420 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3430 REM::::::::::::: acquire augmented wave and average N2 times :::
3440 PAGE
```

```
3450 PRINT "YOU WILL NOW DETERMINE THE CONVOLVED IMPULSE RESPONSES OF"
3460 PRINT
3470 PRINT "THE TRANSMITTING AND RECIEVING ANTENNAS AND THE TARGET."
3480 PRINT
3490 PRINT "IS THE IMAGE PLANE SET-UP AND TARGET IN PLACE? PRESS"
3500 PRINT
3510 PRINT """RETURN"" WHEN READY."
3520 PRINT
3530 INPUT B$
3540 GOSUB 2030
3550 C=X0
3560 FIND @22:52
3570 WRITE @22:X0
3580 PRINT "GGG"
3590 RETURN
3600 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3610 REM:::::::::: SUBROUTINE---SCATWAV :::::::::::::::::::::::::::::::::::
3620 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3630 REM:::::::::: find target backscatter and save ::::::::::::::::::::
3640 X0=C-B
3650 PAGE
3660 FIND @22:53
3670 WRITE @22:X0
3680 IF P0<>7 THEN 3700
3690 P7=1
3700 RETURN
4000 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4010 REM::::::::::::: ANTLOC :::::::::::::::::::::::::::::::::::::::::::::::
4020 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4030 REM::::::::::::: recall antenna parameters from storage :::::::::
4031 DIM A5(63)
4040 FIND @22:VAL(G$)+4
4050 READ @22:A5
4060 RETURN
4100 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
4110 REM:::::::::::::: SUBROUTINE---TGTLOC ::::::::::::::::::::::::::::::
4120 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4130 REM:::::::::::::: recall target parameters from storage ::::::::::
4140 FIND @22:VAL(H$)+25
4149 READ @22:C5,C6
4150 A7=VAL(H$)*3
4151 S9=A5(A7-1)
4152 S6=A5(A7)*(VAL(F$)/1.27)↑2
4153 C7=A5(A7-2)
4160 RETURN
4200 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4210 REM:::::::::::::: SUBROUTINE---NEWPAR ::::::::::::::::::::::::::::::
4220 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4230 REM:::::::::::::: input new target or antenna parameters ::::::::
4240 PAGE
4250 GOSUB C1 OF 4400,4700
4260 FIND @22:VAL(C$)
4261 IF C1=1 THEN 4272
4270 WRITE @22:C2,C3,C4
4271 GO TO 4280
4272 WRITE @22:A5
4280 PRINT "ANY MORE INPUTS? (Y=YES, N=NO)"
4290 INPUT A$
4300 IF A$="N" THEN 4320
4310 GO TO 4250
4320 DELETE C1,C2,C3,C4,C5,A5
4330 RETURN
4400 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4410 REM:::::::::::::: SUBROUTINE---ANTIN :::::::::::::::::::::::::::::::
4420 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4430 REM:::::::::::::: driver for NEWPAR to input new antenna ::::::::
4440 DIM A5(63)
4450 A5=0
4451 FOR I=1 TO 61 STEP 3
```

```
4461 NEXT I
4470 PRINT "INPUT NEW ANTENNA NO."
4480 INPUT C5
4490 IF C5+4>24 THEN 4520
4500 C$=STR(C5+4)
4510 GO TO 4600
4520 PRINT
4530 PRINT "STORAGE AREA LIMITED TO 20 ANTENNAS.  WANT TO CONTINUE?"
4540 INPUT A$
4550 IF A$="N" THEN 4600
4560 PRINT
4570 PRINT "INPUT NEW ANTENNA NUMBER LESS THAN OR EQUAL TO 20."
4580 PRINT
4590 GO TO 4470
4600 RETURN
4700 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4710 REM::::::::::::: SUBROUTINE---TGTIN ::::::::::::::::::::::::::::
4720 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4730 REM::::::::::::: driver for NEWPAR to input new target :::::::::
4740 PRINT "INPUT NEW TARGET NUMBER."
4750 INPUT C5
4760 C$=STR(C5+25)
4770 PRINT
4780 PRINT "INPUT LENGTH AND RADIUS."
4790 INPUT C2,C3
4791 C4=0
4800 RETURN

SPACE
 24552
```

APPENDIX D

LIST OF MATH PROGRAM

A. GENERAL DESCRIPTION

1. Location: File 3

2. Memory space required (less mass storage): 14544-bytes

3. Maximum no. of steps: 206 (169 less remarks)

4. Description: MATH performs the significant mathematical computations for the operating system. These are fast Fourier and inverse Fourier transformations, determination of impulse, step, and ramp responses, noise optimization and compensation, and antenna parameter determination. Inputs are from File 2, File 4 and mass storage. Output is to File 4 and mass storage. This program is competely automated with no operator-processor interactions.

B. LOCAL PROGRAM VARIABLES AND CONSTANTS

1. Significant

TYPE	NAME	USE	REMARKS
ARRAY	B0	OPTIC DRIVER	(512)--METRIC PHYSICAL OPTICS FROM RAMP RESPONSE
ARRAY	E	DRIVER	(257)--FREQUENCY DOMAIN BACKSCATTER MAG.
ARRAY	E0	DRIVER	(257)--FREQUENCY DOMAIN IMPULSE RESPONSE PHASE
ARRAY	E3	DRIVER	(257)--FREQUENCY DOMAIN BACKSCATTER PHASE
ARRAY	F	DRIVER	(257)--FREQUENCY DOMAIN DIRECT WAVE MAG.
ARRAY	F0	DRIVER	(257)--FREQUENCY DOMAIN IMPULSE RESPONSE MAG.
ARRAY	F3	DRIVER	(257)--FREQUENCY DOMAIN DIRECT WAVE PHASE
ARRAY	I0	DRIVER	(512)--TIME DOMAIN TARGET IMPULSE RESPONSE

TYPE	NAME	USE	REMARKS
ARRAY	R0	DRIVER	(512)--TIME DOMAIN RAMP RESPONSE
CONSTANTS	MISC	ALL	MISC CONSTANTS AND VARIABLES

2. Miscellaneous

a. ARRAY: X0(512),M(257),P(257)

b. NUMERIC VARIABLES AND CONSTANTS: I, I3, K, M1, M2, N, N1, P1, P2, Q, Q1, Q2, Q4, S2, S2, U

C. MEMORY REQUIREMENTS

1. 4052 Internal Memory Requirements

DESCRIPTION	BYTES
EACH ACQUIRED WAVEFORM TO BE AVERAGED	4114
FREQUENCY DOMAIN BACKSCATTER PHASE	2074
FREQUENCY DOMAIN BACKSCATTER MAG	2074
FREQUENCY DOMAIN DIRECT WAVE PHASE	2074
FREQUENCY DOMAIN DIRECT WAVE MAG	2074
FREQUENCY DOMAIN IMPULSE PHASE	2074

DESCRIPTION	BYTES
FREQUENCY DOMAIN IMPULSE MAG	2074
EACH ACQUIRED WAVEFORM TO BE AVERAGED	4114
FREQUENCY DOMAIN TEMP STORAGE PHASE	2074
FREQUENCY DOMAIN TEMP STORAGE MAG	2074
TIME DOMAIN TARGET IMPULSE RESPONSE	4114
TIME DOMAIN RAMP RESPONSE	4114
PHYSICAL OPTICS FROM RAMP RESPONSE	4114
SCATCH PAD TEMPORARY STORAGE	4114
VARIOUS NUMERIC/STRING VARIABLES AND CONSTANTS	1516
TOTAL	34564
MAXIMUM MEMORY REQUIREMENTS (INTERNAL) FOR INPUT	49108

D. EXTERNAL MASS STORAGE REQUIREMENTS (DATA TAPE)

DESCRIPTION	BYTES	FILE #
FREQUENCY DOMAIN IMPULSE RESPONSE	4148	56
FREQUENCY DOMAIN DIRECT WAVEFORM	4148	55
FREQUENCY DOMAIN BACKSCATTER	4148	57
TIME DOMAIN IMPULSE RESPONSE	4114	54
PHYSICAL OPTICS FROM RAMP RESPONSE	4114	58
TIME DOMAIN RAMP RESPONSE	4114	59
GRAPHING PARAMETERS	8364	60
TOTAL	29036	

E. SUBROUTINES

CLASS	NAME	LINE	STEPS	%	DESCRIPTION
DRIVER	DRIVER	100-1210	122	59	INITIALIZE AND DRIVE PROGRAM. PASS CONTROL TO NEXT FILE
	FFT	2000-2140	15	7	PERFORMS FAST FOURIER TRANSFORM
	OPTIC	2200-2700	51	25	SEPERATES TARGET FROM RANGE NOISE
	ANTUP	3000-3080	9	4	UPDATES ANTENNA PARAMETERS
	OPTIM	3100-3180	9	4	COMPENSATES PHYSICAL OPTICS OPTIMIZATION

```
97 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
96 REM:::::: FILE 3 ::::::: MATH :::::: 8-01-81 ::::::::::
99 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
100 REM::::::::: initialize main program driver :::::::::::::::::::::
110 L=0
120 L1=1
130 IF S4=1 THEN 210
140 FIND @22:60
150 DIM W(4)
151 W=0
160 READ @22:P$,E$,F$,G$,H$,X$,R$,M$,T$,P8,P7,21,N2,C5,C6,C7,T1
170 READ @22:S1,S4,S5,S6,L1,L,W
180 IF P7=1 THEN 200
190 READ @22:B7,B6,B8,Q7,Q9
200 L=L2
210 DIM E0(257),E(257),F0(257),F(257),M(257),P(257),E3(257),F3(257)
220 DIM X0(512),I0(512),W(4)
221 W=0
230 REM::::::::: fourier transform of target backscatter ::::::::::::
240 FIND @22:53
250 READ @22:X0
260 GOSUB 2060
270 E=M
280 E3=P
290 REM::::::::: fourier transform of direct wave ::::::::::::::::::
300 FIND @22:50
310 READ @22:X0
320 GOSUB 2060
330 F=M
340 F3=P
350 P=P*-1
360 REM::::::::: frequency domain impulse response//optimization ::::
370 E0=E*F
380 F0=F↑2
```

```
390 F0=F0+L
400 E0=E0/F0
410 PAGE
420 F0=E3+P
430 REM:::::::::: initialize data for inverse fourier transformation :
440 FOR J=2 TO 256
450 M(J)=E0(J)*COS(F0(J))
460 P(J)=E0(J)*SIN(F0(J))
470 NEXT J
480 M(1)=0
490 M(257)=0
500 P(1)=0
510 P(257)=0
520 CALL "INLEAV",M,P,I0
530 REM:::::::::: time domain impulse response :::::::::::::::::::::::
540 CALL "IFT",I0
550 I3=SUM(I0)/512
560 I0=I0-I3
580 DELETE M,P
590 DIM R0(512),B0(512)
600 REM:::::::::: store time impulse and fourier transforms :::::::::
610 X0=I0
620 FIND @22:54
630 WRITE @22:I0
640 IF P7=1 THEN 710
650 FIND @22:55
660 WRITE @22:F,F3
670 FIND @22:56
680 WRITE @22:E,E3
690 FIND @22:57
700 WRITE @22:E0,F0
710 DELETE E,F,E3,F3,I0,E0,F0
720 IF P7=1 THEN 1090
730 REM:::::::::: step response ::::::::::::::::::::::::::::::::::::::
740 CALL "INT",X0,X0
```

```
750 X3=SUM(X0)/512
760 X0=X0-X3
770 REM:::::::::: ramp response ::::::::::::::::::::::::::::::::::::::::
780 CALL "INT",X0,R0
790 CALL "MIN",R0,R2,I
800 REM:::::::::: find physical optics of target//compensate distance:
810 GOSUB 2200
880 IF S4<>1 OR H$="???" THEN 910
890 REM:::::::::: update antenna parameters ::::::::::::::::::::::::::
900 GOSUB 3000
910 B0=B0*S6
920 CALL "MIN",B0,B8,I
930 IF L1<>1 THEN 970
940 B6=B8
950 Q9=W(2)-W(1)
960 REM:::::::::: compensate for optimization effects on optics ::::::
970 GOSUB 3100
980 L1=0
990 REM::::::::: save antenna parameters for targets :::::::::::::::
999 IF S4=0 OR H$="???" THEN 1040
1000 A7=VAL(H$)*3
1001 DIM A5(63)
1002 FIND @22:VAL(G$)+4
1003 READ @22:A5
1004 A5(A7-2)=C7+1
1005 A5(A7-1)=S5
1006 A5(A7)=S6/(Z6/1.27)↑2
1007 A5(62)=A5(62)+S5
1008 A5(63)=A5(63)+S6/(Z6/1.27)↑2
1009 A5(61)=A5(61)+1
1020 FIND @22:VAL(G$)+4
1030 WRITE @22:A5
1031 REM:::::::: save optic and ramp response :::::::::::::::::::::::
1040 FIND @22:58
1050 WRITE @22:B0
```

```
1060 FIND @22:59
1070 WRITE @22:R0
1080 DELETE B0,R0,X0
1090 S4=0
1100 FIND @22:60
1110 WRITE @22:P$,E$,F$,G$,H$,X$,R$,M$,T$,P8,P7,Z1,N2,C5,C6,C7,T1
1120 WRITE @22:S1,S4,S5,S6,L1,L,W
1130 IF P7=1 THEN 1160
1140 WRITE @22:B7,B6,B8,Q7,Q9
1150 REM::::::::: end routine ::::::::::::::::::::::::::::::::::::::::::
1160 DELETE X0,R0,B0,P$,F$,G$,H$,X$,R$,P8,P7,Z1,N2,C5,C6,C7,T1,S4,L1,S6
1170 DELETE E$,B7,B6,B8,Q7,Q9,M$,T$,S1,L,X,W,Z6,A5,A7,S5
1180 FIND 4
1190 CALL "LINK",100
1200 REM/////////////////////////////////////////////////////////////////
1210 REM////////// END MATH PROGRAM--GO TO GRAPH PROGRAM //////
1980 REM/////////////////////////////////////////////////////////////////
1990 REM////////// END DRIVER //////////////////////////////////////
2000 REM/////////////////////////////////////////////////////////////////
2010 REM////////// BEGIN SUBROUTINES ///////////////////////////////
2020 REM/////////////////////////////////////////////////////////////////
2030 REM::::::::: SUBROUTINE--FFT :::::::::::::::::::::::::::::::::::::::
2040 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2050 REM::::::::: fast fourier transform routine :::::::::::::::::::::::
2060 CALL "FFT",X0
2070 CALL "POLAR",X0,M,P
2120 RETURN
2200 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2210 REM::::::::: SUBROUTINE--OPTICS ::::::::::::::::::::::::::::::::::
2220 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2230 REM::::::::: seperate target response from range response :::::::
2240 B0=0
2250 R3=SUM(R0)/512
2260 R3=R3*0.9
2270 N=1
```

```
2280 N1=512
2290 FOR K=I TO N1 STEP N
2300 B0(K)=R0(K)
2310 IF B0(K)<0 THEN 2350
2320 B0(K)=0
2330 K=K-1
2340 GO TO 2510
2350 IF R0(K)>R0(K-N) AND R0(K)>R3 OR R0(K)<=R3 THEN 2500
2360 W(3)=R0(K-2*N)-R0(K-N)
2370 Q2=R0(K-N)-W(3)*10
2380 IF Q2>0 THEN 2400
2390 W(3)=R0(K-N)/10
2400 Q1=W(3)
2410 REM::::::::: determine endpoint boundaries of optics :::::::::::
2420 FOR Q=K TO N1 STEP N
2430 B0(Q)=B0(Q-N)-Q1
2440 IF B0(Q)<0 THEN 2470
2450 B0(Q)=0
2460 GO TO 2480
2470 NEXT Q
2480 K=Q
2490 GO TO 2510
2500 NEXT K
2510 IF N<>1 THEN 2560
2520 N1=1
2530 N=-1
2540 W(2)=K
2550 GO TO 2290
2560 W(1)=K
2570 REM::::::::: compensate for geometric range losses :::::::::::::
2580 Z6=VAL(F$)
2581 IF W(1)<>0 THEN 2590
2582 W(1)=1
2590 FOR Q=W(1) TO W(2)
2600 R=(Q-W(1))*Z1*3.0E+8/2
```

```
2610 U=(Z6+R)*(2*Z6+R)/(2*Z6↑2)
2620 R0(Q)=R0(Q)*U
2630 B0(Q)=B0(Q)*U
2640 NEXT Q
2650 Q4=0
2660 FOR Q=W(1) TO 512
2670 Q4=Q4+1
2680 B0(Q4)=B0(Q)
2690 NEXT Q
2700 RETURN
3000 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3010 REM::::::::: SUBROUTINE--ANTUP ::::::::::::::::::::::::::::::::::::::::::::
3020 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3030 REM::::::::: determine antenna parameter update :::::::::::::::::::::::::::
3040 CALL "MIN",B0,B2,I
3050 S2=S5
3060 S6=(C6/ABS(B2)-S6)/C7+S6
3070 S5=(C5/(Z1*(W(2)-W(1))*1.2E+10)-S2)/C7+S2
3080 RETURN
3100 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3110 REM::::::::: SUBROUTINE--OPTIM ::::::::::::::::::::::::::::::::::::::::::::
3120 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3130 REM::::::::: pin optic graph to original boundaries ::::::::::::::::::::::
3140 B7=B6/B8
3150 Q7=(W(2)-W(1))/Q9
3160 B0=B0*B7
3170 CALL "MAX",B0,B8,I
3180 RETURN

SPACE
 14544
```

21	NEW		768
22	BINARY DATA	TGT 1	768
23	BINARY DATA	TGT 2	768
24	BINARY DATA	TGT 3	768
25	BINARY DATA	TGT 4	768
26	BINARY DATA	TGT 5	768
27	BINARY DATA	TGT 6	768
28	BINARY DATA	TGT 7	768
29	BINARY DATA	TGT 8	768
30	BINARY DATA	TGT 9	768
31	BINARY DATA	TGT10	768
32	BINARY DATA	TGT11	768
33	NEW		768
34	NEW		768
35	NEW		768
36	NEW		768
37	NEW		768
38	NEW		768
39	NEW		768
40	NEW		768
41	NEW		768
42	LAST		768

```
REM::FILE LOCATIONS OF ANTENNAS--TAPE #2::

TLIS

1       BINARY  DATA        ANT 1   768

2       BINARY  DATA        ANT 2   768

3       BINARY  DATA        ANT 3   768

4       BINARY  DATA        ANT 4   768

5       BINARY  DATA        ANT 5   768

6       BINARY  DATA        ANT 6   768

7       BINARY  DATA        ANT 7   768

8       BINARY  DATA        ANT 8   768

9       BINARY  DATA        ANT 9   768

10      BINARY  DATA        ANT10   768

11      BINARY  DATA        ANT11   768

12      BINARY  DATA        ANT12   768
 13      BINARY  DATA                768
 14      BINARY  DATA                768
 15      BINARY  DATA                768
 16      BINARY  DATA                768
 17      BINARY  DATA                768
 18      BINARY  DATA                768
 19      BINARY  DATA                768
 20      BINARY  DATA                768
```

APPENDIX E

LIST OF GRAPH PROGRAM

A. GENERAL DESCRIPTION

1. Location: File 4

2. Memory space required (less mass storage): 44712-bytes

3. Maximum no. of steps: 584 (473 less remarks)

4. Description: GRAPH provides the means to visually display the results of signal acquisition and processing. Subroutines are divided into three classes:

   a) GENERAL--those subroutines that are applicable to most of the other routines in GRAPH. They initialize the program, format graphics, title, lable, and overlay a grid.

   b) INVERSE SCATTERING--those routines applicable to the inverse scattering solution of time domain electromagnetic transients. They are the secondary drivers for the development of graphics.

c) PRONY'S TECHNIQUE--routines applicable to the Prony method of solution.

Inputs to GRAPH are from File 3, File 7, the GS keyboard and mass storage. Outputs are to the GS CRT, mass storage, File 2, File 3, File 6, and File 8. This program is highly operator-processor interactive. Numerous messages and directives guide the user. Signicant graphs are provided for operator evaluation of processing results.

B. LOCAL PROGRAM VARIABLES AND CONSTANTS

1. Significant

TYPE	NAME	USE	REMARKS
ARRAY	X	VARIOUS	(512)--TEMPORARY STORAGE AND PROCESSING
ARRAY	Y	VARIOUS	(512)--TEMPORARY STORAGE AND PROCESSING
ARRAY	P	AXIS TICKS AXLAB	(8)--AXIS LABLING

TYPE	NAME	USE	REMARKS
CONSTANTS	S0	ALL	FLAG
CONSTANTS	L$	ALL	HORIZONTAL AXIS LABLE
CONSTANTS	N$	ALL	VERTICAL AXIS LABLE
CONSTANTS	P0	ALL	MENU ITEM
CONSTANTS	L2	DRIVER	OPTIMIZATION FACTOR
CONSTANTS	A0	GROP	HORIZONTAL SCALING FACTOR
CONSTANTS	A1	GROP	VERTICAL SCALING FACTOR
CONSTANTS	C	GROP	SCALING VIEWPORT COMPENSATOR

2. <u>Miscellaneous</u>

a. ARRAY: none

b. STRING CONSTANTS: A$, B$, S$

c. NUMERIC VARIABLES AND CONSTANTS: D5, G1, G2, G3, G4, C5, I, J, Q, P1, P2, P3, P4, V1, V2, V3, V4, W1, W2, W3, W4, W5, W6

C. MEMORY REQUIREMENTS

1. 4052 Internal Data Storage

DESCRIPTION	BYTES
VARIOUS TEMPORARY STORAGE/PROCESSING	8228
MATRIX LABLING ARRAY	82
VARIOUS NUMERIC/STRING VARIABLES AND CONSTANTS	1566
TOTAL	9866
MAXIMUM MEMORY REQUIREMENTS (INTERNAL) FOR INPUT	54578

2. External Mass Storage Requirements (Data Tape): none

D. SUBROUTINES

CLASS	NAME	LINE	STEPS	%	DESCRIPTION
DRIVER	DRIVER	100-1190	110	19	INITIALIZE AND DRIVE PROGRAM. PASS CONTROL TO NEXT FILE
GRAPH	AXIS	2000-2250	26	4	DRIVES AXIS GRAPHING,
GRAPH	TICKS	2300-	22	5	AXIS TICKS INTERVALS

CLASS	NAME	LINE	STEPS	%	DESCRIPTION
GRAPH	AXLAB	2700-3190	50	9	LABLE VERTICAL AND HORIZONTAL AXIS
GRAPH	TITLE	3200-3310	12	2	POSITION GRAPH TITLE
GRAPH	GRPAR	3400-3870	48	8	PRINTS PARAMETER VALUES AS REQUIRED
GRAPH	GRID	3900-4010	12	2	DRAWS GRIDS
INVERSE SCATTER	GRIN	5000-5410	42	7	GRAPHICS FOR DIRECT, INCIDENT, AUGMENTED AND BACKSCATTER TIME DOMAIN WAVES
INVERSE SCATTER	GRFOUR	5500-6080	59	10	GRAPHICS FOR FREQ DOMAIN PHASE AND MAGNITUDE OF DIRECT, BACKSCATTER AND IMPULSE RESPONSE
INVERSE SCATTER	GROP	6100-5410	43	8	GRAPHICS FOR PHYSICAL OPTICS OF TARGET
INVERSE SCATTER	GRAMP	6600-6910	32	5	GRAPHICS FOR RAMP RESPONSE

CLASS	NAME	LINE	STEPS	%	DESCRIPTION
PRONY	PRIMP	7000-7340	35	6	GRAPHICS FOR IMPULSE RESPONSE
PRONY	PROTRAN	7400-7710	32	5	GRAPHICS FOR PRONY TRANSIENT RESPONSE
PRONY	PROLES	7800-8300	51	9	GRAPHICS FOR PRONY POLES OF IMPULSE

```
100 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
110 REM::::::::: FILE 4 ::::::: GRAPHING ::::::: 8-01-81 ::::::::::::::
120 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
130 REM::::::::: PROGRAM DRIVER :::::::::::::::::::::::::::::::::::::::::
140 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
150 REM::::::::: initialize program driver :::::::::::::::::::::::::::::
160 PAGE
170 IMAGE 15X,45A
180 IMAGE 7A,8X,45A
190 IMAGE 3X,30A,1X,+4D.2D,1X,4A
200 IMAGE 3X,30A,2X,3D.4D,1X,1A,2D.4D,1A
201 IMAGE 3X,30A,2X,3D.4D,1X,1A,2D.4D,1A
210 IMAGE 3X,30A,1X,-D.4D,1X,4A
220 IMAGE 3X,32A,1X,FD
230 FIND @22:60
231 DIM N(4)
240 READ @22:P$,E$,F$,G$,H$,X$,R$,M$,T$,P8,P7,Z1,N2,C5,C6,C7,T1
250 READ @22:S1,S4,S5,S6,L1,L,W
260 IF P7=1 THEN 280
270 READ @22:B7,B6,B8,Q7,Q9
280 IMAGE 3A,1X,8A,1X,6A,1X,3A,1X,4A,1X,32A
290 PAGE
300 DIM P(8)
310 REM::::::::: select program function from menu :::::::::::::::::
320 IF P7=0 THEN 350
330 PRINT USING 170:"PRONY'S METHOD--GRAPHING"
340 GO TO 360
350 PRINT USING 170:"INVERSE SCATTERING--GRAPHING"
360 PRINT
370 PRINT
380 PRINT USING 180:"1","DIRECT WAVEFORM"
390 PRINT
400 PRINT USING 180:"2","INCIDENT WAVEFORM"
410 PRINT
```

```
420 PRINT USING 180:"3","AUGMENTED WAVEFORM"
430 PRINT
440 PRINT USING 180:"4","SCATTERED WAVEFORM"
450 PRINT
460 IF P7=1 THEN 570
470 PRINT USING 180:"5","MAGNITUDE AND PHASE OF FFT OF DIRECT WAVE"
480 PRINT
490 PRINT USING 180:"6","MAGNITUDE AND PHASE OF FFT OF SCATTERED WAVE"
500 PRINT
510 PRINT USING 180:"7","MAGNITUDE AND PHASE OF FFT OF IMPULSE"
520 PRINT
530 PRINT USING 180:"8","PHYSICAL OPTICS DRAWING OF TARGET"
540 PRINT
550 PRINT USING 180:"9","TIME DOMAIN RAMP RESPONSE OF TARGET"
560 PRINT
570 PRINT USING 180:"10","CONTINUE OPTIMIZATION"
580 PRINT
590 PRINT USING 180:"11","NEXT TARGET"
600 PRINT
610 PRINT USING 180:"12","FINISHED GRAPHING"
620 PRINT
630 IF P7<>1 THEN 720
640 PRINT USING 180:"13","FIND POLES OF TARGET"
650 PRINT
660 PRINT USING 180:"14","PRONY TRANSIENT RESPONSE"
670 PRINT
680 PRINT USING 180:"15","IMPULSE RESPONSE"
690 PRINT
700 PRINT USING 180:"16","EXTRACTED PRONY POLES"
710 PRINT
720 PRINT USING 180:"17","INVERSE SCATTERING SOLUTION"
730 PRINT
740 PRINT
750 PRINT USING 170:"ENTER PROGRAM AND PRESS ""RETURN"""
760 INPUT P0
```

```
770 PAGE
780 V1=0
790 V2=115
800 V3=0
810 V4=58
820 REM::::::::: go to selected graphing routine ::::::::::::::::::::
830 IF P0<10 THEN 860
840 IF P0>9 AND P0<13 THEN 900
850 IF P0>12 THEN 880
860 GOSUB P0 OF 5010,5010,5010,5010,5500,5500,5500,6100,6600
870 GO TO 910
880 GOSUB P0-12 OF 1120,7400,7000,7800,1090
890 GO TO 910
900 GO TO P0-9 OF 950,1040,1170
910 PRINT "GGGG"
920 INPUT B$
930 REM::::::::: return to menu ::::::::::::::::::::::::::::::::::::::
940 GO TO 290
950 REM::::::::: optimize waveform--go to file 3 ::::::::::::::::::::
960 PRINT "DECONVOLUTION IN THE PRESENCE OF NOISE MAY INTRODUCE"
970 PRINT "UNWANTED ERRORS IN THE RAMP AND IMPULSE RESPONSES.  SELECT"
980 PRINT "AN OPTIMUM COMPENSATING VALUE TO MINIMIZE THESE ERRORS."
990 PRINT "LAMBDA = ";
1000 INPUT L2
1010 DELETE P,M,E,F,E0,F0,E3,F3,B0,R0,I0,X
1020 FIND 3
1030 CALL "LINK",130
1040 REM::::::::: go to file 2 for new target run ::::::::::::::::::::
1050 DELETE W,G,P
1060 FIND 2
1070 CALL "LINK",180
1080 REM::::::::: go to file 8 for computing theoretical scatter :::::
1090 INIT
1100 FIND 8
1110 CALL "LINK",100
```

```
1120 REM:::::::: exit file 4 to file 6 for PRONY'S method :::::::::
1130 INIT
1140 FIND 6
1150 CALL "LINK",100
1160 REM:::::::: end routine ::::::::::::::::::::::::::::::::::::::
1170 END
1180 REM//////////////////////////////////////////////////////////
1190 REM///////// END DRIVER /////////////////////////////////
1960 REM//////////////////////////////////////////////////////////
1970 REM///////// BEGIN SUBROUTINES //////////////////////////
1980 REM//////////////////////////////////////////////////////////
1990 REM:::::::: SUBROUTINES FOR GENERAL PROGRAM ::::::::::::::::::
2000 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2010 REM:::::::: SUBROUTINE--AXIS :::::::::::::::::::::::::::::::
2020 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2030 REM:::::::: labled neat axis tick marks ::::::::::::::::::::::
2040 VIEWPORT V1+6*1.8,V2,V3+3*2.8,V4
2050 P(1)=W1
2060 P(2)=W2
2070 P(3)=INT((V2-(V1+6*1.8))/(8*1.8)) MAX 1
2080 P(5)=W3
2090 P(6)=W4
2100 P(7)=INT((V4-(V3+3*2.8))/(3*2.8)) MAX 1
2110 REM:::::::: calculate new limits and intervals:::::::::::::::
2120 P5=3
2130 GOSUB 2340
2140 P5=7
2150 GOSUB 2340
2160 WINDOW P(1),P(2),P(5),P(6)
2170 REM:::::::: establish axis :::::::::::::::::::::::::::::::::::
2180 AXIS P(3)/2,P(7)/2
2190 P5=4
2200 A$="HHHJJ"
2210 GOSUB 2710
2220 P5=8
```

```
2230 A$="ЦЦЦЦЦ"
2240 GOSUB 2710
2250 RETURN
2300 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2310 REM::::::::: SUBROUTINE--TICKS ::::::::::::::::::::::::::::::::::
2320 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2330 REM::::::::: P(P5) = minimum no. of axis ticks ::::::::::::::::::
2340 P1=(P(P5-1)-P(P5-2))/P(P5)
2350 P2=10↑INT(LGT(P1))
2360 P1=P1/P2
2370 IF P1>2 THEN 2420
2380 IF P1=1 THEN 2450
2390 P2=2*P2
2400 GO TO 2450
2410 IF P1>5 THEN 2440
2420 P2=5*P2
2430 GO TO 2450
2440 P2=10*P2
2450 REM::::::::: adjust data minimum ::::::::::::::::::::::::::::::::
2460 P1=INT(P(P5-2)/P2)
2470 P3=P2*(P1+2)
2480 IF P3<P(P5-2) THEN 2510
2490 P3=P3-P2
2500 GO TO 2480
2510 P(P5-2)=P3
2520 REM::::::::: adjust data maximum ::::::::::::::::::::::::::::::::
2530 P1=INT(P(P5-1)/P2)
2540 P3=P2*(P1-2)
2550 IF P(P5-1)<P3 THEN 2580
2560 P3=P3+P2
2570 GO TO 2550
2580 P(P5-1)=P3
2590 REM::::::::: P(P5) = adjusted tick interval :::::::::::::::::::::
2600 P(P5)=P2
2610 RETURN
```

```
2700 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2710 REM::::::::: SUBROUTINE--AXLAB ::::::::::::::::::::::::::::::::::::::
2720 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
2730 REM::::::::: correctly number each axis tick and scale ::::::::::
2740 P4=P(P5-1)
2750 P(4)=P(1)
2760 P(8)=P(5)
2770 P3=ABS(P(P5-3)+P4) MAX ABS(P(P5-2)-P4)
2780 IF P3=0 THEN 2800
2790 P3=INT(LGT(P3)+1.0E-8)
2800 P2=10↑-P3
2810 P1=P(P5-2)-P4/2
2820 P(P5)=P(P5)+P4
2830 IF P(P5)>P1 THEN 3020
2840 MOVE P(4),P(8)
2850 PRINT A$;
2859 REM::::::::: correct format for axis lables :::::::::::::::::::::
2860 IF S0=1 THEN 2930
2861 IF P0<5 OR P0>7 THEN 2880
2862 IF L$="RAD" THEN 2865
2863 PRINT USING "-3D.2D,S":P(P5)*P2/0.1
2864 GO TO 2820
2865 PRINT USING "-D.D,S":P(P5)*P2
2866 GO TO 2820
2880 IF S1*10<1000 THEN 2910
2890 PRINT USING "-D.2D,S":P(P5)*P2
2900 GO TO 2920
2910 PRINT USING "-3D,S":P(P5)*P2*100
2920 GO TO 3010
2930 IF P(6)>10 THEN 3000
2940 IF P(6)=>1 THEN 2980
2950 PRINT "HH"
2960 PRINT USING "-D.4D,S":P(P5)
2970 GO TO 3010
2980 PRINT USING "-FD.2D,S":P(P5)
```

```
2990 GO TO 3010
3000 PRINT USING "-4D,S":P(P5)
3010 GO TO 2820
3020 IF P3=0 THEN 3040
3030 P(P5)=P1
3040 MOVE P(4),P(8)
3050 IF S0=0 THEN 3090
3060 MOVE 0,P(6)
3070 PRINT "KH"
3080 GO TO 3180
3090 PRINT "JJ";
3100 IF S0=1 THEN 3130
3110 S$=L$
3120 GO TO 3140
3130 S$=N$
3140 IF P0>4 AND P0<8 THEN 3170
3141 IF P0=16 THEN 3161
3150 PRINT USING "2X,4A,S":S$
3160 GO TO 3180
3161 PRINT USING "2A,+FD,4A,S":"E";P3;S$
3162 GO TO 3180
3170 IF S0=1 THEN 3173
3171 PRINT USING "7A,S":S$
3172 GO TO 3180
3173 PRINT USING "4A,S":S$
3180 S0=S0+1
3190 RETURN
3200 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3210 REM::::::::: SUBROUTINE--TITLE ::::::::::::::::::::::::::::::::::
3220 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3230 REM::::::::: appropriate title for graph positioned :::::::::::::
3240 MOVE W2/2,P(6)
3250 PRINT "K";
3260 FOR J=1 TO LEN(A$)/2
3270 PRINT "H";
```

```
3280 NEXT J
3290 PRINT A$
3300 HOME
3310 RETURN
3400 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3410 REM:::::::::: SUBROUTINE--GRPAR :::::::::::::::::::::::::::::::::::
3420 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3430 REM:::::::::: format labling parameters for each graph :::::::::::
3440 PRINT "    TARGET: ";
3450 PRINT USING 280:R$,"DATE","DIST","ANT","TGT","REMARKS"
3460 PRINT "           ";
3470 PRINT USING 280:P$,E$,F$,G$,H$,X$
3480 IF P0>12 THEN 3500
3490 GO TO P0 OF 3510,3510,3510,3510,3830,3830,3830,3710,3510
3500 GO TO P0-13 OF 3620,3620,3760
3510 PRINT
3520 PRINT USING 190:"MAXIMUM PEAK VALUE............";W4;N$
3530 PRINT
3540 PRINT USING 190:"MINIMUM PEAK VALUE............";W3;N$
3550 PRINT
3560 PRINT USING 190:"RMS VALUE.....................";W6;N$
3570 PRINT
3580 PRINT USING 190:"MEAN VALUE....................";W5;N$
3590 PRINT
3600 GO TO 3830
3610 REM:::::::::: impulse response parameter format lables ::::::::::
3620 PRINT
3630 PRINT USING 210:"MAXIMUM PEAK VALUE............";W4;N$
3640 PRINT
3650 PRINT USING 210:"MINIMUM PEAK VALUE............";W3;N$
3660 PRINT
3670 PRINT USING 210:"RMS VALUE.....................";N6;N$
3680 PRINT
3690 PRINT USING 210:"MEAN VALUE....................";W5;N$
3700 GO TO 3830
```

```
3710 REM:::::::: dimensions for physical optics ::::::::::::::::::::
3720 PRINT USING 201:"DIAMETER (INCHES-CORRECTED)";W4*2;"(";C6*2;")"
3730 W8=(W(2)-W(1))*Z1*1.2E+10/2
3740 PRINT USING 200:"WIDTH (INCHES-CORRECTED)";W2;"(";C5;")"
3741 PRINT USING 200:"WIDTH (INCHES-UNCORRECTED)**";W8;"(";C5;")"
3750 GO TO 3830
3760 REM:::::::: lables for Prony pole graph :::::::::::::::::::::::
3770 PRINT USING 220:"NO OF PRONY POLES EXTRACTED=";C
3780 PRINT
3790 PRINT USING 220:"STEP SIZE= ";X1
3800 PRINT
3810 PRINT USING 220:"DATA POINTS USED= ";INT(512/X1)
3820 REM:::::::: continue general labling ::::::::::::::::::::::::::
3830 PRINT "NUMBER OF WAVEFORMS AVERAGED = ";N2;
3840 PRINT "      ";"OPTIMIZATION VALUE = ";L
3850 PRI "--------------------------------------------------------";
3860 PRINT "----------"
3870 RETURN
3900 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3910 REM::::::::: SUBROUTINE--GRID ::::::::::::::::::::::::::::::::
3920 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
3930 REM::::::::: draw grid lines for graphs ::::::::::::::::::::::
3940 FOR J=P(5) TO P(6) STEP P(7)
3950 AXIS 0,0,0,J
3960 NEXT J
3970 FOR I=P(1) TO P(2) STEP P(3)
3980 AXIS 0,0,I,0
3990 NEXT I
4000 AXIS 0,0,P(2),P(6)
4010 RETURN
4980 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
4990 REM:::::::: SUBROUTINES FOR INVERSE SCATTERING ::::::::::::::::
5000 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
5010 REM:::::::: SUBROUTINE--GRIN :::::::::::::::::::::::::::::::::
5020 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
5030 REM::::::::: graph input waveforms :::::::::::::::::::::::::::::::
5040 DIM X(512),Y(512)
5050 FIND @22:49+P0
5060 READ @22:X
5070 REM::::::::: waveform parameters ::::::::::::::::::::::::::::::::::
5080 X=X*1000
5090 S0=0
5100 L$=T$
5110 N$=N$
5120 W1=0
5130 W2=Z1*512
5140 W5=SUM(X)/512
5150 X=X-W5
5160 W5=SUM(X)/512
5170 CALL "MIN",X,W3,I
5180 CALL "MAX",X,W4,I
5190 Y=X*X
5200 W6=SQR(SUM(Y)/512)
5210 REM::::::::: draw graph ::::::::::::::::::::::::::::::::::::::::::
5220 GOSUB 2000
5230 MOVE 9*Z1,X(9)
5240 FOR Q=9 TO 512
5250 DRAW Q*Z1,X(Q)
5260 NEXT Q
5270 GOSUB 3910
5280 REM::::::::: lable graph :::::::::::::::::::::::::::::::::::::::::
5290 IF P0<>4 THEN 5320
5300 A$="BACK SCATTER WAVE FORM"
5310 GO TO 5390
5320 IF P0<>3 THEN 5350
5330 A$="AUGMENTED WAVEFORM"
5340 GO TO 5390
5350 IF P0<>2 THEN 5380
5360 A$="INCIDENT WAVEFORM"
5370 GO TO 5390
```

```
5380 A$="DIRECT WAVEFORM"
5390 GOSUB 3200
5400 GOSUB 3400
5401 DELETE X,Y
5410 RETURN
5500 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
5510 REM:::::::: SUBROUTINE--GRFOUR :::::::::::::::::::::::::::::::::::
5520 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
5530 REM:::::::: graph fourier transform of scattered wave magnitude
5540 DIM X(257),Y(257)
5550 FIND @22:P0+50
5560 READ @22:X,Y
5561 FOR J=61 TO 257
5562 X(J)=0
5563 NEXT J
5570 REM:::::::: waveform parameters :::::::::::::::::::::::::::::::::
5580 S0=0
5590 L$="    GHZ"
5600 N$=" "
5610 V3=45
5620 V4=80
5630 W1=0
5640 W2=60/(Z1*512)
5650 CALL "MIN",X,W3,I
5660 CALL "MAX",X,W4,I
5670 REM:::::::: graph waveform ::::::::::::::::::::::::::::::::::::::
5680 GOSUB 2000
5690 MOVE 0,0
5700 FOR Q=1 TO 60
5710 DRAW Q/(Z1*512),X(Q)
5720 NEXT Q
5721 GOSUB 3910
5730 REM:::::::: lable waveform ::::::::::::::::::::::::::::::::::::::
5740 GO TO P0-4 OF 5750,5770,5790
5750 A$="DIRECT FFT--MAGNITUDE"
```

```
5760 GO TO 5800
5770 A$="SCATTERED FFT--MAGNITUDE"
5780 GO TO 5800
5790 A$="IMPULSE FFT--MAGNITUDE"
5800 GOSUB 3200
5810 GOSUB 3400
5820 REM:::::::: graph fourier transform of scattered wave phase :::
5830 REM:::::::: waveform parameters :::::::::::::::::::::::::::::::
5840 S0=0
5850 L$="RAD"
5860 H$=" "
5870 W1=0
5880 W2=2*PI
5890 CALL "MIN",Y,W3,I
5900 CALL "MAX",Y,W4,I
5910 V3=0
5920 V4=35
5930 REM:::::::: graph waveform :::::::::::::::::::::::::::::::::::
5940 GOSUB 2000
5950 MOVE 0,Y(1)
5960 FOR Q=1 TO 257
5970 DRAW Q*2*PI/257,Y(Q)
5980 NEXT Q
5981 GOSUB 3910
5990 REM:::::::: lable waveform :::::::::::::::::::::::::::::::::::
6000 GO TO P0-4 OF 6010,6030,6050
6010 A$="DIRECT FFT--PHASE"
6020 GO TO 6060
6030 A$="SCATTERED FFT--PHASE"
6040 GO TO 6060
6050 A$="IMPULSE FFT--PHASE"
6060 GOSUB 3200
6070 DELETE X,Y
6080 RETURN
6100 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
6110 REM::::::::: SUBROUTINE--GROP :::::::::::::::::::::::::::::::::::::
6120 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
6130 REM::::::::: graph physical optics response of target ::::::::::
6131 DELETE C
6140 DIM X(512)
6150 FIND @22:58
6160 READ @22:X
6170 REM::::::::: waveform parameters ::::::::::::::::::::::::::::::
6180 S0=0
6210 W1=0
6220 W2=Z1*(W(2)-W(1))*1.2E+10*S5/Q7
6230 CALL "MIN",X,W3,I
6240 W4=W3*-1
6260 VIEWPORT 10,120,0,74
6270 WINDOW W1,W2,W3,W4
6280 REM::::::::: determine axis scaling for true 1 to 1 relationship
6290 A0=(W2-W1)/(V2-V1-5)
6300 A1=A0
6310 C=1
6320 IF (V4-V3)*A0>2*W4 THEN 6370
6330 C=A0*(V4-V3)/(2*W4)
6340 X=X*C
6370 MOVE 0,X(1)
6380 SCALE A0,A1
6390 REM::::::::: graph waveform ::::::::::::::::::::::::::::::::::::
6400 FOR Q=1 TO 512
6410 U1=Q*Z1*1.2E+10*C*S5/Q7
6420 DRAW U1,X(Q)
6430 DRAW U1,-X(Q)
6440 IF X(Q)=X(Q+5) THEN 6470
6450 NEXT Q
6460 REM::::::::: lable waveform ::::::::::::::::::::::::::::::::::::
6470 A$="                RAMP RESPONSE -- PHYSICAL OPTICS"
6480 HOME
6490 GOSUB 3400
```

```
6500 PRINT A$
6510 DELETE X,C,U1,A0,A1
6520 RETURN
6600 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
6610 REM::::::::: SUBROUTINE--GRAMP :::::::::::::::::::::::::::::::::
6620 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
6630 REM::::::::: graph time domain ramp response of target :::::::::
6640 DIM X(512),Y(512)
6650 FIND @22:59
6660 READ @22:X
6670 X=X*1000
6680 REM::::::::: waveform parameters :::::::::::::::::::::::::::::::
6690 S0=0
6700 L$=T$
6710 N$=M$&"-M"
6720 W1=0
6730 W2=Z1*512
6740 CALL "MIN",X,W3,I
6750 CALL "MAX",X,W4,I
6760 W5=SUM(X)/512
6770 Y=X*X
6780 W6=SQR(SUM(Y)/512)
6790 REM::::::::: graph waveform ::::::::::::::::::::::::::::::::::::
6800 GOSUB 2000
6810 MOVE 0,X(1)
6820 FOR Q=1 TO 512
6830 DRAW Q*Z1,X(Q)
6840 NEXT Q
6850 GOSUB 3910
6860 REM::::::::: lable waveform ::::::::::::::::::::::::::::::::::::
6870 A$="RAMP RESPONSE -- TIME"
6880 GOSUB 3200
6890 GOSUB 3400
6900 DELETE X,Y
6910 RETURN
```

```
6980 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
6990 REM::::::::: SUBROUTINES FOR PRONY'S METHOD ::::::::::::::::::::
7000 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
7010 REM:::::::: SUBROUTINE--PRIMP :::::::::::::::::::::::::::::::::::::
7020 REM:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
7030 REM:::::::: graph time domain impulse response of target ::::::
7040 DIM X(512),Y(512)
7050 FIND @22:54
7060 READ @22:X
7070 REM:::::::: waveform parameters ::::::::::::::::::::::::::::::::
7080 S0=0
7090 L$=T$
7100 N$=M$
7110 W1=0
7120 W2=Z1*512
7130 CALL "MIN",X,W3,I
7140 CALL "MAX",X,W4,I
7150 W5=SUM(X)/512
7160 X=X-W5
7170 W5=SUM(X)/512
7180 Y=X*X
7190 W6=SQR(SUM(Y)/512)
7200 V1=5
7210 V2=120
7220 DELETE Y
7230 REM::::::::: graph waveform ::::::::::::::::::::::::::::::::::::::
7240 GOSUB 2000
7250 MOVE 0,X(1)
7260 FOR Q=1 TO 512
7270 DRAW Q*Z1,X(Q)
7280 NEXT Q
7290 GOSUB 3910
7300 REM:::::::: lable waveform ::::::::::::::::::::::::::::::::::::::
7310 A$="IMPULSE RESPONSE"
7320 GOSUB 3200
```

```
7330 GOSUB 3400
7331 DELETE X
7340 RETURN
7400 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
7410 REM:::::::: SUBROUTINE--PROTRAN ::::::::::::::::::::::::::::::::::::
7420 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
7430 FIND @22:61
7440 READ @22:G1,G2,G3,G4,T2,D5
7450 DIM G(T2)
7460 READ @22:G
7470 REM:::::::: waveform parameters :::::::::::::::::::::::::::::::::::
7480 S0=0
7490 L$=T$
7500 N$=M$
7510 W1=0
7520 W2=Z1*512
7530 W3=G1
7540 W4=G2
7550 W5=G3
7560 W6=G4
7570 V1=5
7580 V2=120
7590 REM:::::::: graph waveform :::::::::::::::::::::::::::::::::::::::
7600 GOSUB 2000
7610 MOVE 0,G(1)
7620 FOR Q=1 TO T2 STEP D5
7630 DRAW Q*Z1,G(Q)
7640 NEXT Q
7650 GOSUB 3910
7660 REM:::::::: lable graph ::::::::::::::::::::::::::::::::::::::::::
7670 A$="PRONY TRANSIENT RESPONSE"
7680 GOSUB 3200
7690 GOSUB 3400
7700 DELETE G
7710 RETURN
```

```
7800 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
7810 REM::::::::: SUBROUTINE--PROLES ::::::::::::::::::::::::::::::::
7820 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
7830 ON SIZE THEN 7832
7831 GO TO 7840
7832 A0=ABS(W4/W2)
7833 RETURN
7840 FIND @22:62
7850 READ @22:C,X1
7860 DIM X(C),Y(C)
7870 READ @22:X,Y
7880 REM::::::::: waveform parameters :::::::::::::::::::::::::::::::
7890 S0=0
7900 L$=" "
7910 N$=" "
7920 CALL "MIN",X,W1,I
7930 CALL "MAX",X,W2,I
7940 CALL "MIN",Y,W3,I
7950 CALL "MAX",Y,W4,I
7960 REM::::::::: scale axis ::::::::::::::::::::::::::::::::::::::::
7970 PRINT "DO YOU WANT TO SET SCALES FOR THE GRAPH? TYPE Y=YES, N=NO."
7980 INPUT B$
7990 IF B$="N" THEN 8100
8000 PRINT
8010 PRINT "INPUT TIME SCALING. Tmax = ";
8020 INPUT W2
8030 PRINT "                    Tmin = ";
8040 INPUT W1
8050 PRINT
8060 PRINT "INPUT AMPLITUDE SCALING. Amax = ";
8070 INPUT W4
8080 PRINT "                         Amin = ";
8090 INPUT W3
8100 PAGE
8110 V1=5
```

```
8120 V2=125
8130 V3=5
8140 V4=70
8150 REM:::::::: graph waveform ::::::::::::::::::::::::::::::::::::
8160 GOSUB 2000
8161 GOSUB 3900
8162 A0=ABS(P(6)/P(2))
8170 FOR I=1 TO C
8179 MOVE X(I),Y(I)
8180 IF B$<>"Y" THEN 8190
8181 IF X(I)<P(2) AND X(I)>P(1) THEN 8183
8182 GO TO 8230
8183 IF Y(I)<P(6) AND Y(I)>P(5) THEN 8190
8184 GO TO 8230
8190 SCALE A0,1
8202 RMOVE 0.5*1.55,-0.5*1.88
8210 PRINT "o";
8220 RMOVE 0.5*1.55,0.5*1.88
8230 WINDOW P(1),P(2),P(5),P(6)
8240 NEXT I
8250 REM:::::::: lable waveform ::::::::::::::::::::::::::::::::::::
8260 A$=" "
8270 GOSUB 3200
8280 GOSUB 3400
8290 DELETE X,Y,C,X1
8291 OFF SIZE
8300 RETURN

SPACE
 44712
```

```
97 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
98 REM:::::::: FILE 6 :::::: PRONY 1 :::::::: 7-9-81 :::::::::::::::::
99 REM::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
100 INIT
101 PRINT @32,26:2
110 DIM X0(512),M(512)
120 FIND @22:54
130 READ @22:X0
140 PAGE
150 A=0
160 PRINT
170 PRINT "ENTER NUMBER OF STEPS. D = ";
180 INPUT D
190 FOR J=1 TO 512 STEP D
200 A=A+1
210 M(A)=X0(J)
220 NEXT J
230 DIM M(A),U6(A)
240 U6=M
250 K=A
260 DELETE X0
270 REM ****SOLVE SYSTEM OF LINEAR EQUATIONS(REAL)****
280 REM DATA ENTRY
300 GOSUB 450
310 GOSUB 1720
320 END
330 REM SOLVE SYSTEM
340 GOSUB 1720
350 END
360 REM CORECT MATRIX
370 GO TO 1460
380 REM PRINT MATRIX
390 GOSUB 1580
400 END
```

APPENDIX F

TYPICAL OPERATING SYSTEM PROCEDURE

In this Appendix is presented a typical run in which a sphere and a cone are illuminated by the incident electromagnetic field. The messages presented and the results displayed are those as would be encountered during a normal run of the system.

The OS is first used to acquire and display a normal signal (the sphere). This signal is then optimized to remove noise. The results of the effected waveforms are then represented. Finally, the system is returned to INPUT and a new target, a cone is acquired. The results for the cone are presented. Note that the impulse response is optimized by a factor of .5 while all other graphs for the cone are shown unoptimized.

```
                INVERSE SCATTERING--GRAPHING

1               DIRECT WAVEFORM
2               INCIDENT WAVEFORM
3               AUGMENTED WAVEFORM
4               SCATTERED WAVEFORM
5               MAGNITUDE AND PHASE OF FFT OF DIRECT WAVE
6               MAGNITUDE AND PHHSE OF FFT OF SCATTERED WAVE
7               MAGNITUDE AND PHASE OF FFT OF IMPULSE
8               PHYSICAL OPTICS DRAWING OF TARGET
9               TIME DOMAIN RAMP RESPONSE OF TARGET
10              CONTINUE OPTIMIZATION
11              NEXT TARGET
12              FINISHED GRAPHING
17              INVERSE SCATTERING SOLUTION

                ENTER PROGRAM AND PRESS "RETURN"
10
```

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ +290.00 mV

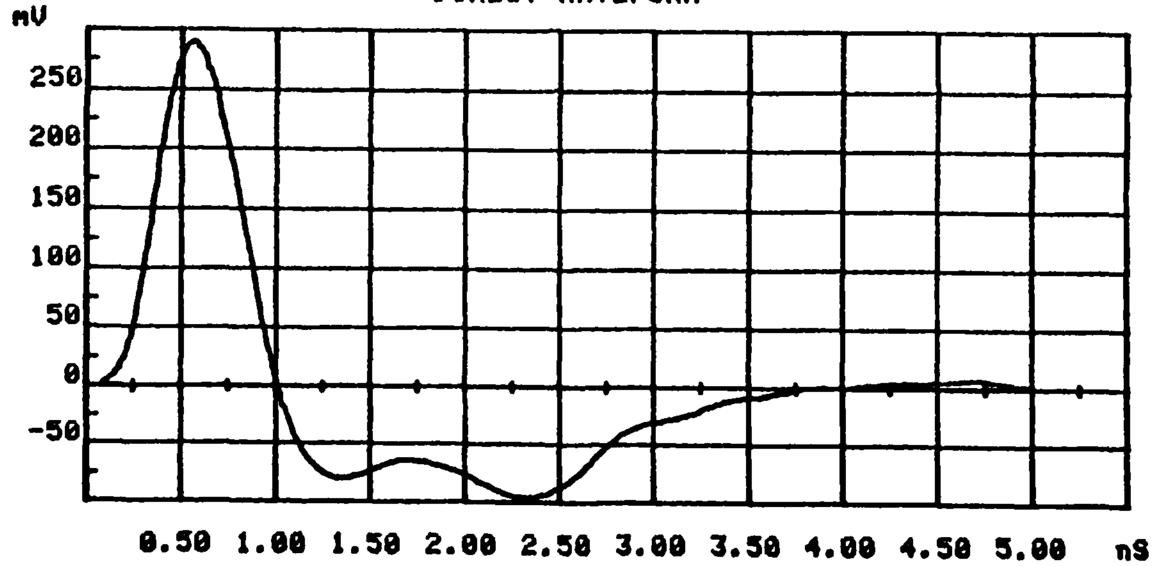
MINIMUM PEAK VALUE............ -96.85 mV

RMS VALUE.................... +90.64 mV

MEAN VALUE...................   0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 4   OPTIMIZATION VALUE = 0

DIRECT WAVEFORM



TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ +4.53 mV

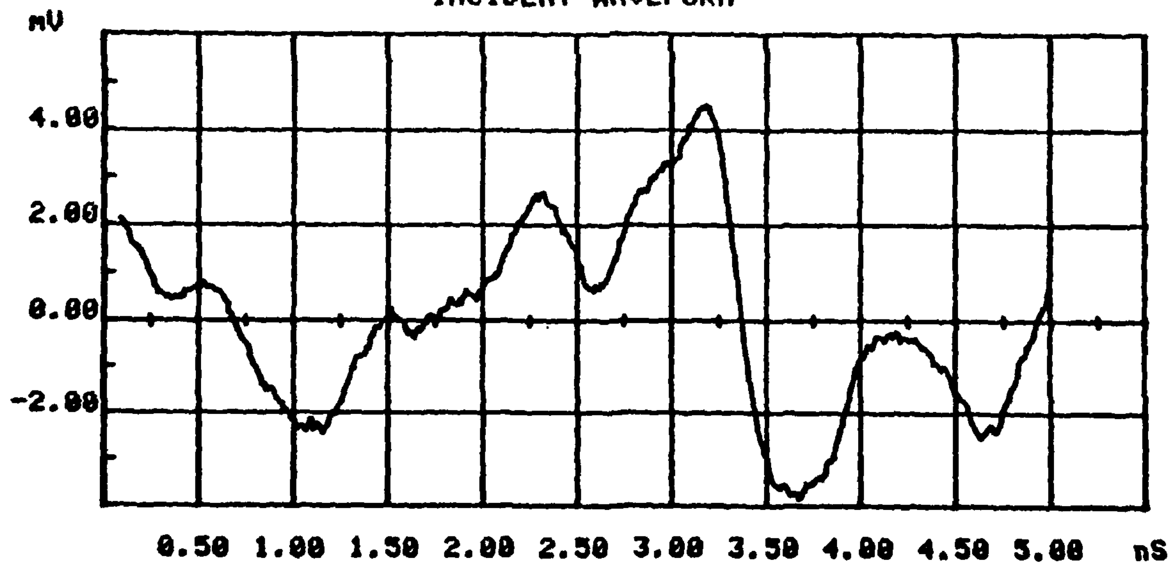
MINIMUM PEAK VALUE............ -3.84 mV

RMS VALUE..................... +1.94 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0

INCIDENT WAVEFORM



TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ +5.86 mV

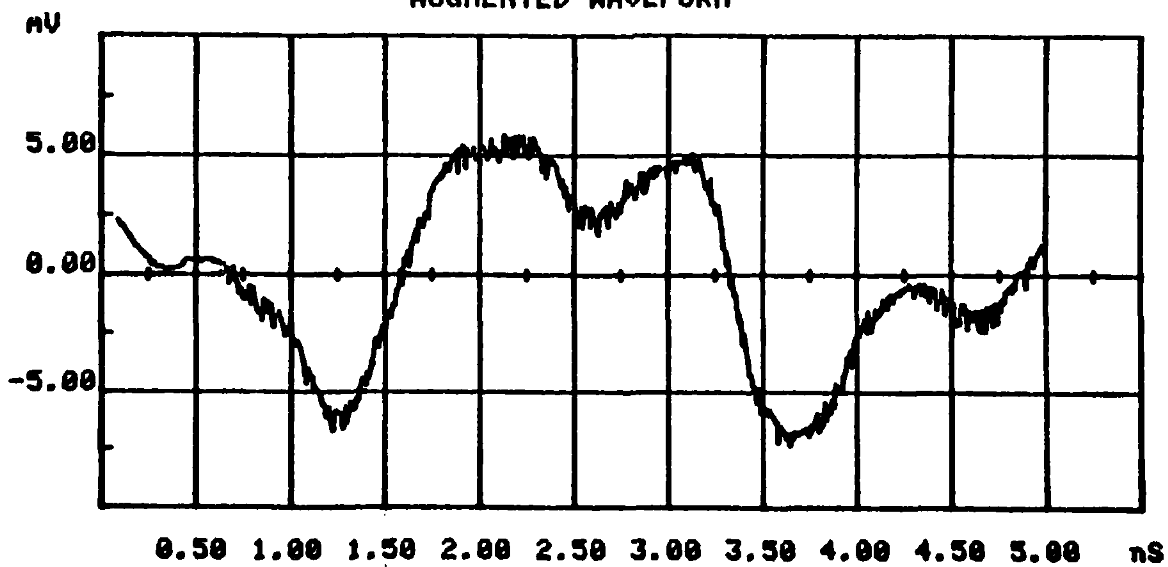
MINIMUM PEAK VALUE............ -7.34 mV

RMS VALUE..................... +3.57 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0

AUGMENTED WAVEFORM



TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ +4.87 mV

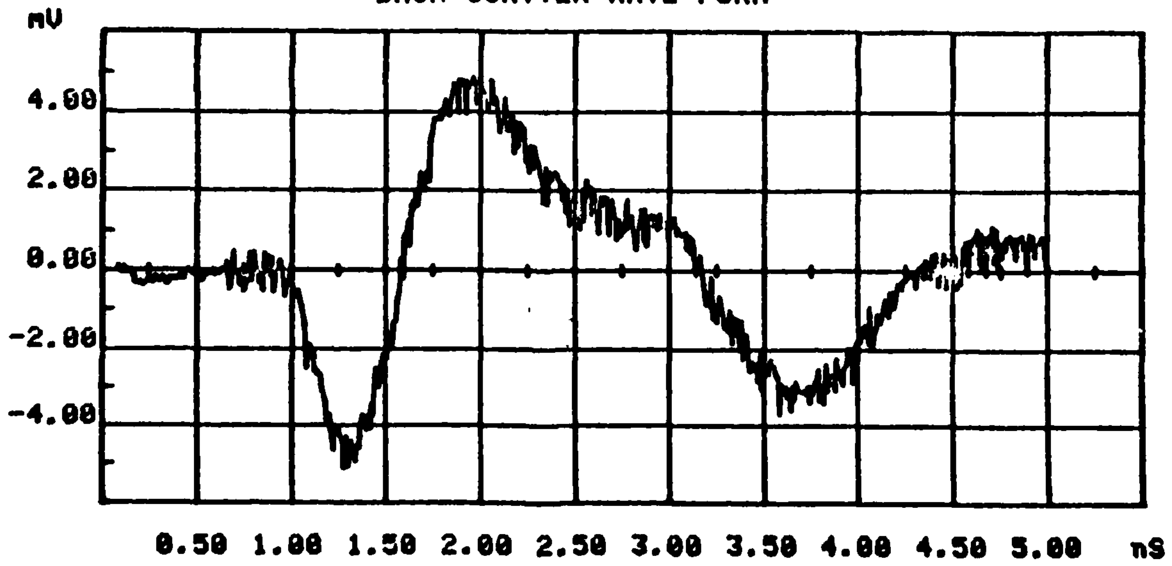
MINIMUM PEAK VALUE............ -5.10 mV

RMS VALUE..................... +2.15 mV

MEAN VALUE.................... 0.00 mV

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0

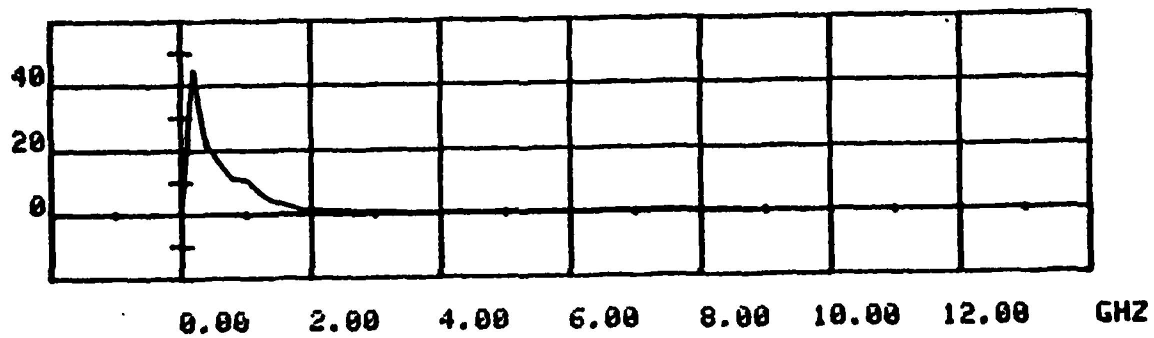
BACK SCATTER WAVE FORM



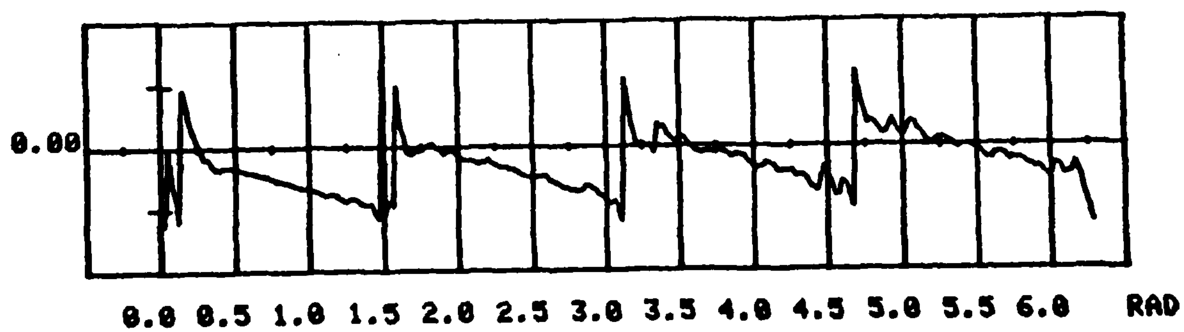
TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0

DIRECT FFT--MAGNITUDE

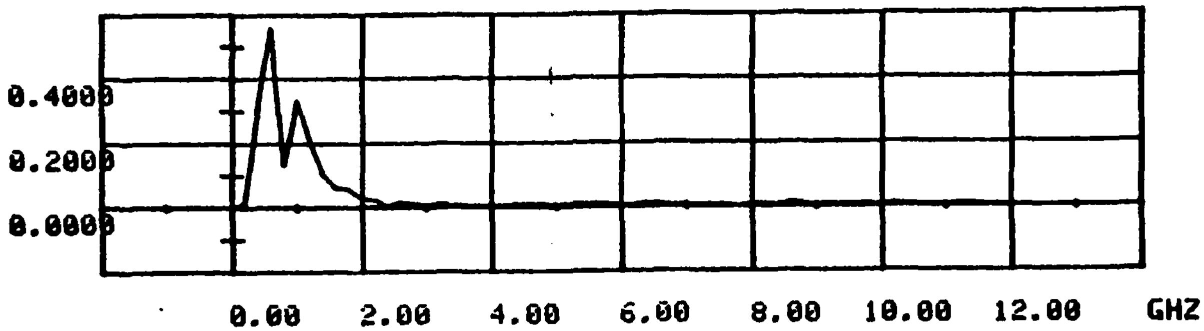


DIRECT FFT--PHASE

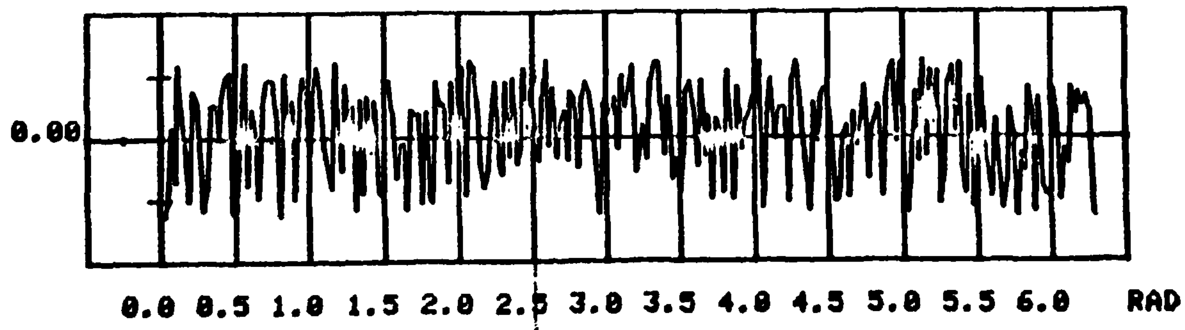


```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
          6  8-11-81  1.27M  1   7    TYPICAL OPERATING SYSTEM USE
NUMBER OF WAVEFORMS AVERAGED = 4      OPTIMIZATION VALUE = 0
```

SCATTERED FFT--MAGNITUDE

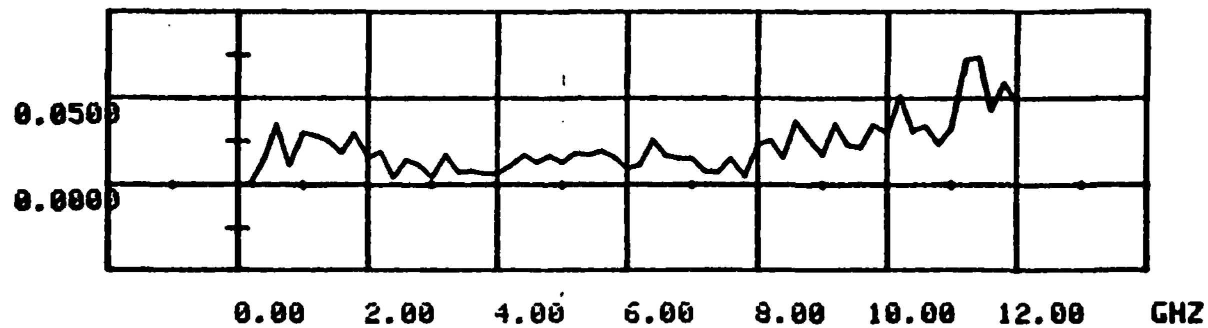


SCATTERED FFT--PHASE

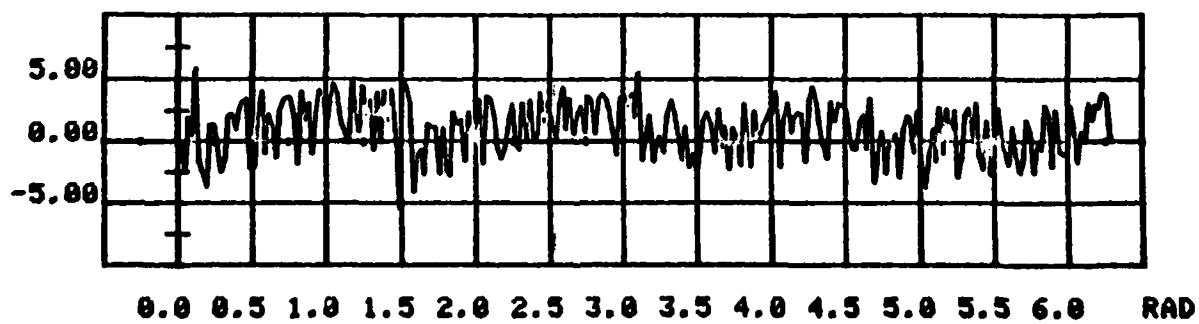


```
   TARGET: RUN DATE      DIST    ANT TGT   REMARKS
             6  8-11-81  1.27M   1    7    TYPICAL OPERATING SYSTEM USE
NUMBER OF WAVEFORMS AVERAGED = 4       OPTIMIZATION VALUE = 0
```

IMPULSE FFT--MAGNITUDE



IMPULSE FFT--PHASE



TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ 0.0166 mV

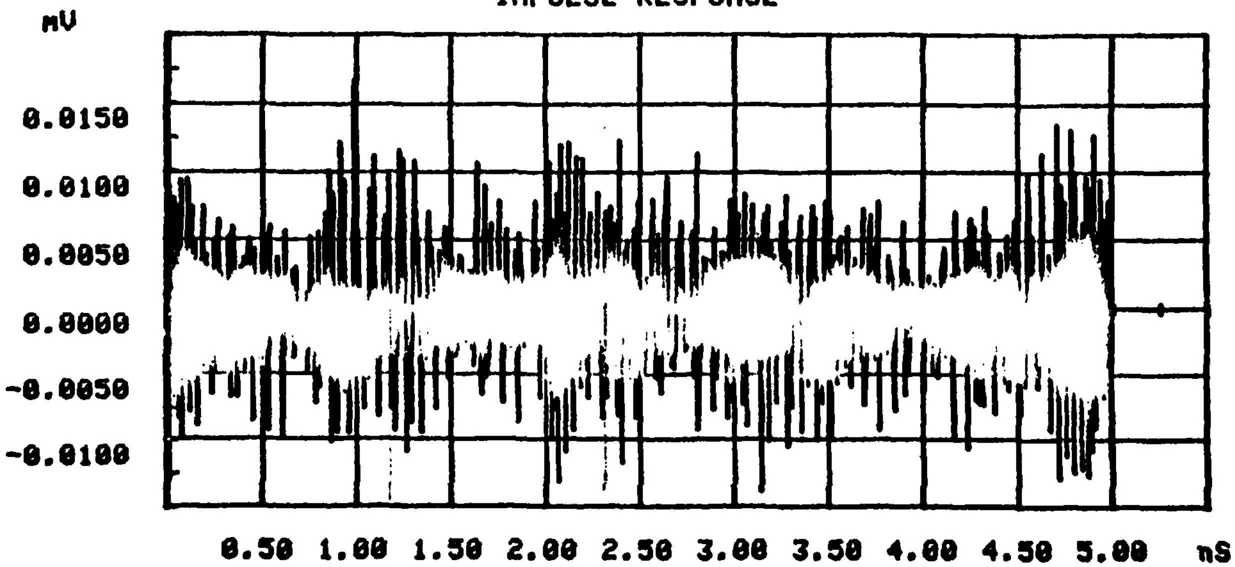
MINIMUM PEAK VALUE............ -0.0137 mV

RMS VALUE.................... 0.0058 mV

MEAN VALUE................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 4   OPTIMIZATION VALUE = 0

IMPULSE RESPONSE



TARGET: RUN	DATE	DIST	ANT	TGT	REMARKS
6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ +36.68 mV-M

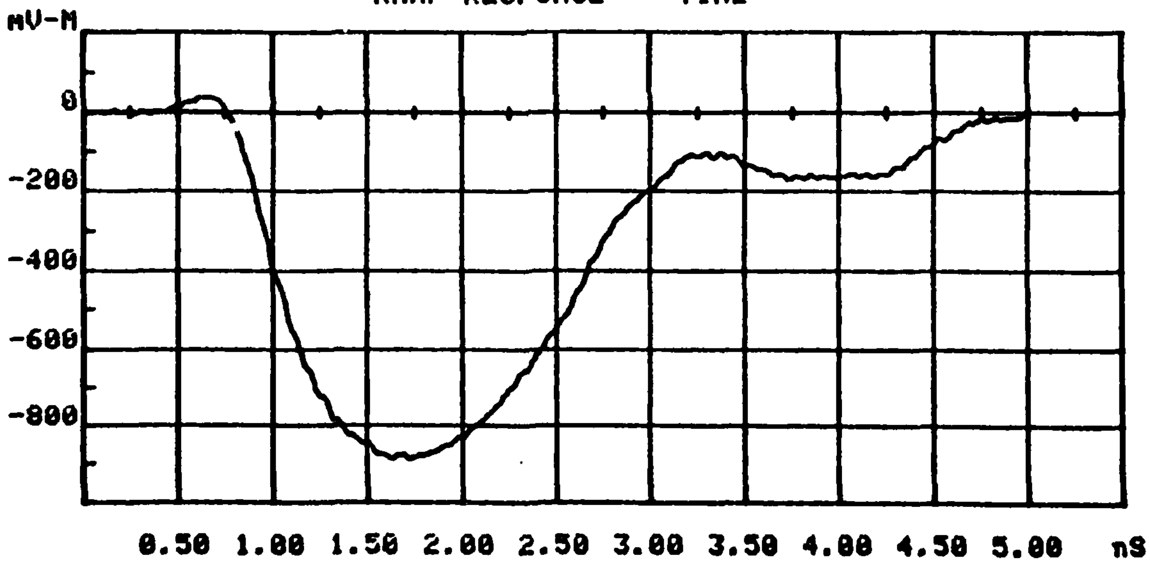
MINIMUM PEAK VALUE............ -886.71 mV-M

RMS VALUE..................... +441.85 mV-M

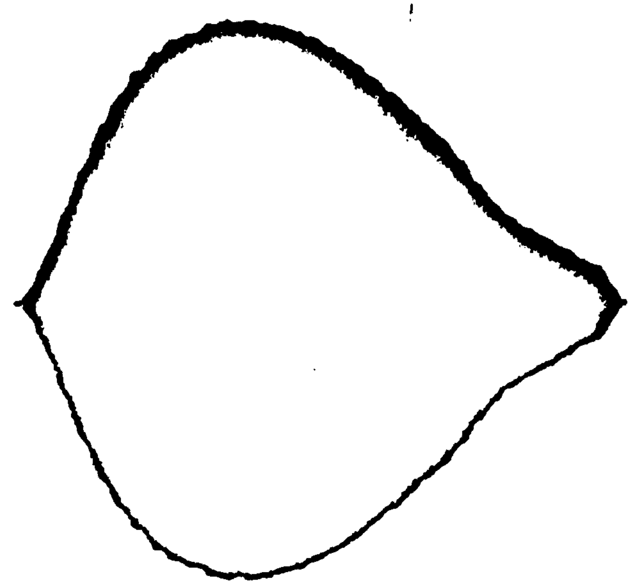
MEAN VALUE.................... -311.75 mV-M

NUMBER OF WAVEFORMS AVERAGED = 4   OPTIMIZATION VALUE = 0

RAMP RESPONSE -- TIME



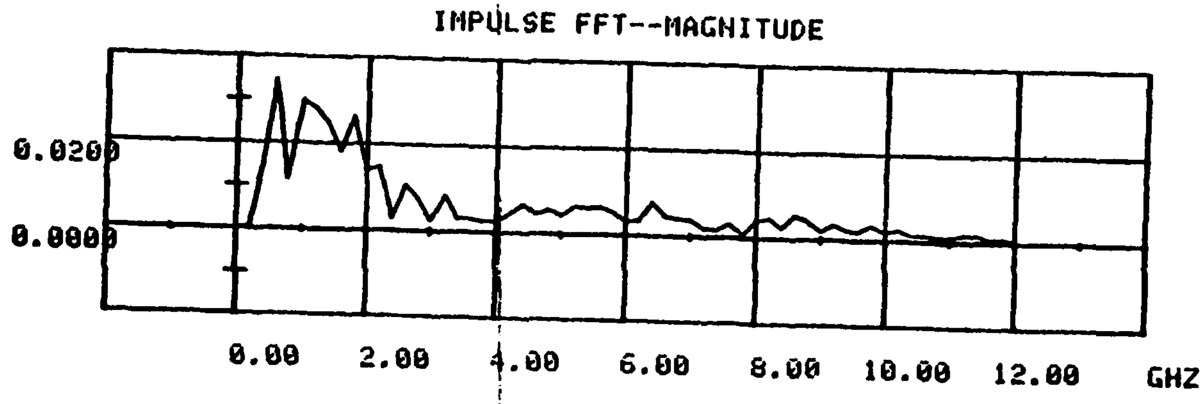
```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
          6  8-11-81  1.27M  1   7    TYPICAL OPERATING SYSTEM USE
   DIAMETER (INCHES-CORRECTED)       9.6158 (10.0000)
   WIDTH (INCHES-CORRECTED)         10.0189 (10.0000)
   WIDTH (INCHES-UNCORRECTED)**     15.5273 (10.0000)
NUMBER OF WAVEFORMS AVERAGED = 4      OPTIMIZATION VALUE = 0
------------------------------------------------------------------
                RAMP RESPONSE -- PHYSICAL OPTICS
```

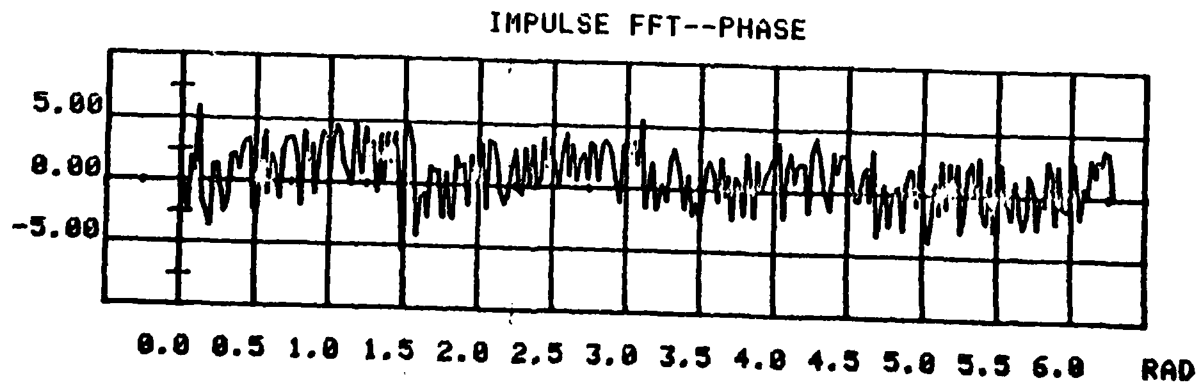


DECONVOLUTION IN THE PRESENCE OF NOISE MAY INTRODUCE
UNWANTED ERRORS IN THE RAMP AND IMPULSE RESPONSES. SELECT
AN OPTIMUM COMPENSATING VALUE TO MINIMIZE THESE ERRORS.
LAMBDA = .5

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0.5





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TIME DOMAIN RADAR LABORATORY OPERATING SYSTEM DEVELOPMENT AND T--ETC(U)

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DATE FILMED

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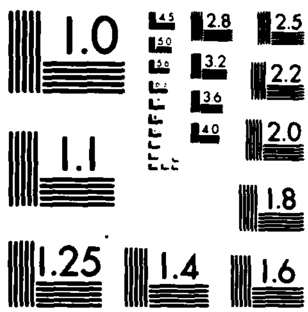


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ 0.0005 mV

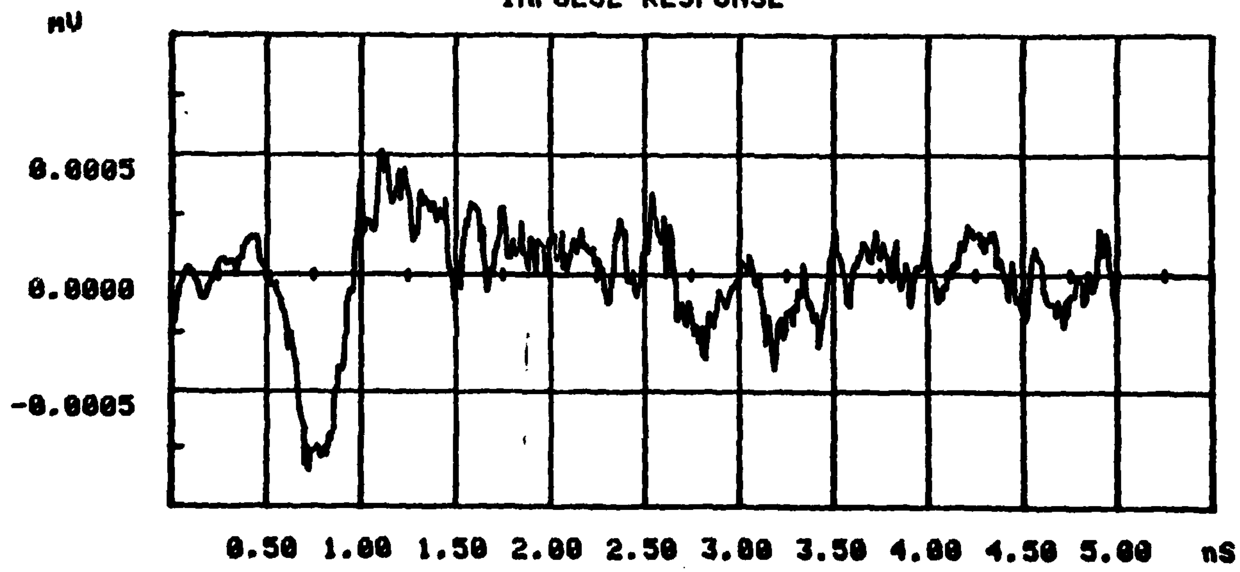
MINIMUM PEAK VALUE............ -0.0008 mV

RMS VALUE..................... 0.0002 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0.5

IMPULSE RESPONSE



TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	6	8-11-81	1.27M	1	7	TYPICAL OPERATING SYSTEM USE

MAXIMUM PEAK VALUE............ +41.38 mV-M

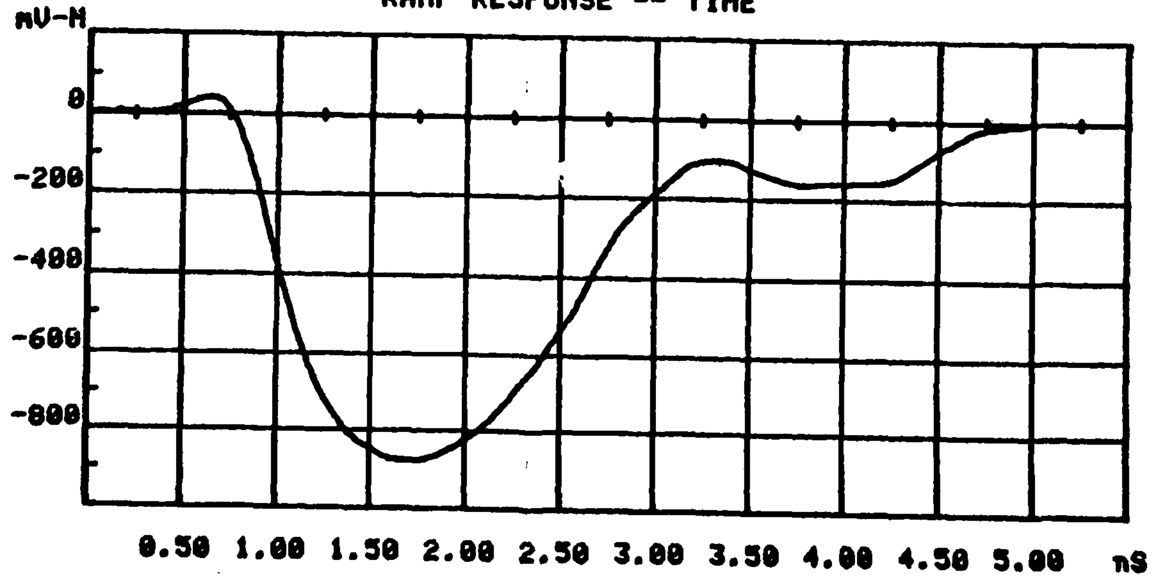
MINIMUM PEAK VALUE............ -877.83 mV-M

RMS VALUE..................... +438.45 mV-M

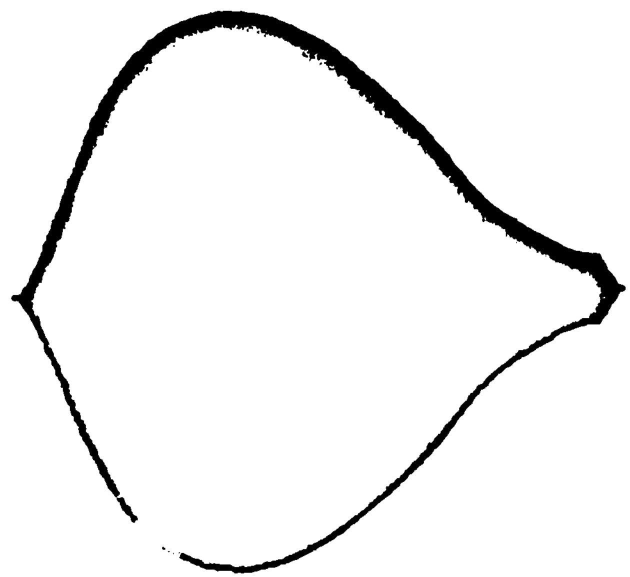
MEAN VALUE.................... -307.44 mV-M

NUMBER OF WAVEFORMS AVERAGED = 4 OPTIMIZATION VALUE = 0.5

RAMP RESPONSE -- TIME



```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
          6  8-11-81  1.27M  1   7    TYPICAL OPERATING SYSTEM USE
  DIAMETER (INCHES-CORRECTED)          9.6158 (10.0000)
  WIDTH (INCHES-CORRECTED)            10.0189 (10.0000)
  WIDTH (INCHES-UNCORRECTED)**        15.9961 (10.0000)
NUMBER OF WAVEFORMS AVERAGED = 4       OPTIMIZATION VALUE = 0.5
-----------------------------------------------------------------
                RAMP RESPONSE -- PHYSICAL OPTICS
```

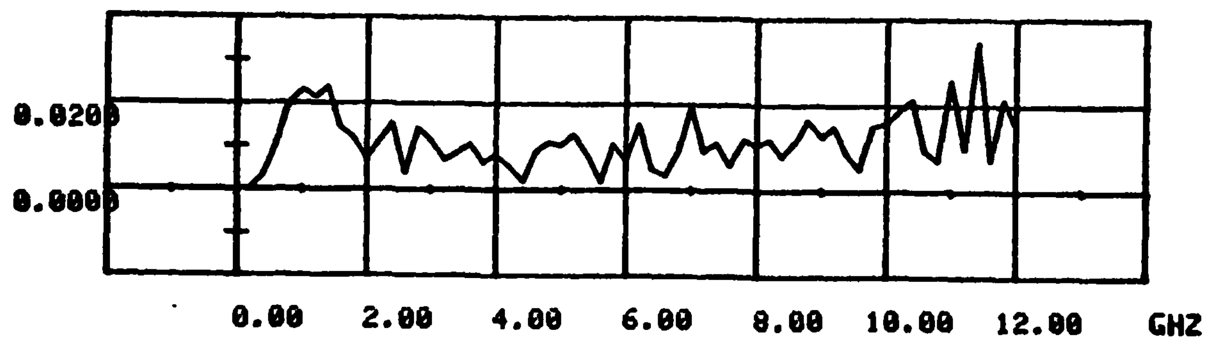


```
DO YOU WANT TO CHANGE DISTANCE PARAMETER? TYPE Y=YES,N=NO.
N
DO YOU WANT TO CHANGE ANTENNA TYPE? TYPE Y=YES, N=NO.
N

DO YOU WANT TO CHANGE TARGETS? TYPE Y=YES, N=N0.
Y
NEW TARGET (??? IF UNKNOWN): 11

BRIEFLY DESCRIBE RUN PURPOSE
CONE--TYPICAL OS USB
```

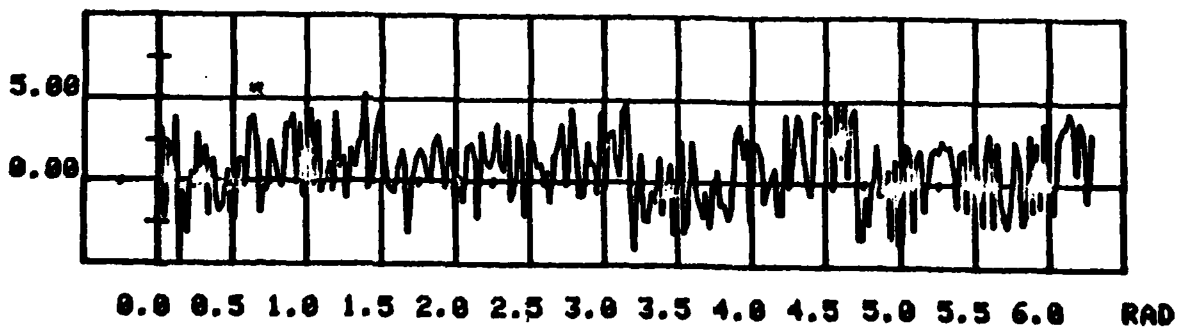
TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	8	8-11-81	1.27M	1	11	CONE--TYPICAL OS USE

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0

IMPULSE FFT--MAGNITUDE



IMPULSE FFT--PHASE



TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	8	8-11-81	1.27M	1	11	CONE--TYPICAL OS USE

MAXIMUM PEAK VALUE............ 0.0006 mV

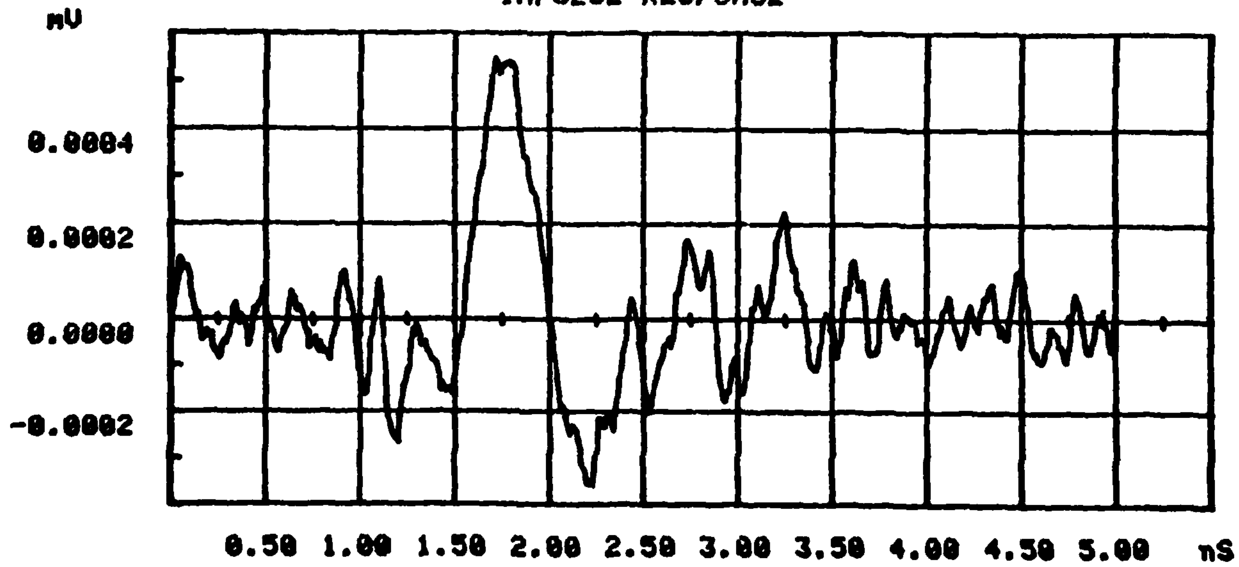
MINIMUM PEAK VALUE............ -0.0004 mV

RMS VALUE..................... 0.0002 mV

MEAN VALUE.................... 0.0000 mV

NUMBER OF WAVEFORMS AVERAGED = 21 OPTIMIZATION VALUE = 0.5

IMPULSE RESPONSE



TARGET:	RUN	DATE	DIST	ANT	TGT	REMARKS
	8	8-11-81	1.27M	1	11	CONE--TYPICAL OS USE

MAXIMUM PEAK VALUE............ +28.41 mV-M

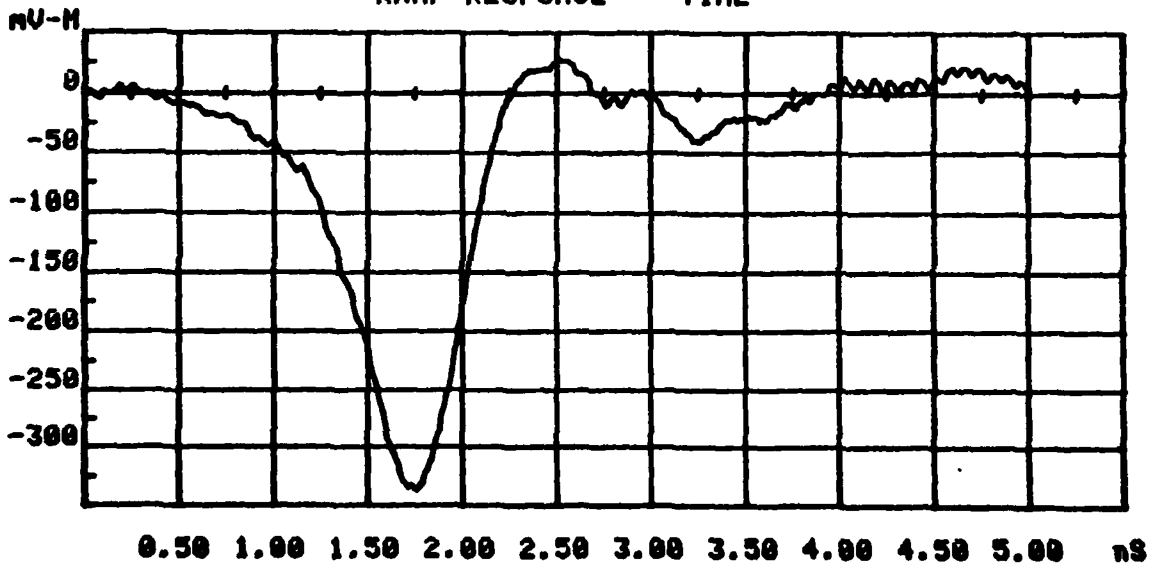
MINIMUM PEAK VALUE............ -336.49 mV-M

RMS VALUE...................... +101.58 mV-M

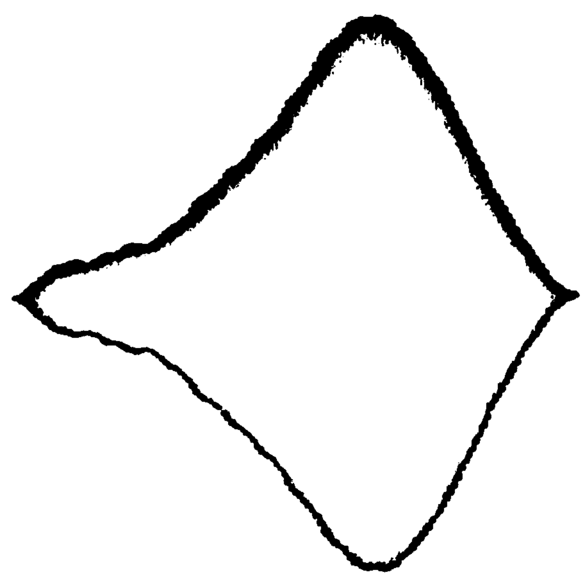
MEAN VALUE..................... -45.29 mV-M

NUMBER OF WAVEFORMS AVERAGED = 21   OPTIMIZATION VALUE = 0

RAMP RESPONSE -- TIME



```
TARGET: RUN DATE     DIST   ANT TGT  REMARKS
          8  8-11-81  1.27M  1   11   CONE--TYPICAL OS USE
  DIAMETER (INCHES-CORRECTED)        6.3905 ( 6.3600)
  WIDTH (INCHES-CORRECTED)           6.1109 ( 5.9400)
  WIDTH (INCHES-UNCORRECTED)**       8.6133 ( 5.9400)
NUMBER OF WAVEFORMS AVERAGED = 21      OPTIMIZATION VALUE = 0
------------------------------------------------------------
              RAMP RESPONSE -- PHYSICAL OPTICS
```



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